# DOCUMENT RESUME

ED 459 587 EF 005 928

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|---|---|
| AUTHOR | Eley, Charles, Ed. |
| TITLE | High Performance Schools Best Practices Manual. Volume I: Planning [and] Volume II: Design [and] Volume III: Criteria. |
| INSTITUTION | Eley Associates, San Francisco, CA. |
| SPONS AGENCY | Collaborative for High Performance Schools, CA. |
| PUB DATE | 2001-00-00 |
| NOTE | 651p.; Version 1.0. |
| AVAILABLE FROM | For full text: www.eley.com/chps/manual/index.htm. |
| PUB TYPE | Guides - Non-Classroom (055) -- Reports - Descriptive (141) |
| EDRS PRICE | MF03/PC27 Plus Postage. |
| DESCRIPTORS | Educational Environment; *Educational Facilities Design; *Elementary Secondary Education; Energy Management; *Guidelines; *Public Schools; *School Effectiveness |
| IDENTIFIERS | *California |

ABSTRACT

This three-volume manual, focusing on California's K-12 public schools, presents guidelines for establishing schools that are healthy, comfortable, energy efficient, resource efficient, water efficient, secure, adaptable, and easy to operate and maintain. The first volume describes why high performance schools are important, what components are involved in their design, and how to successfully navigate the design and construction process of such schools. The second volume contains design guidelines for high performance schools. These guidelines are tailored for California climates and are written for the architects and engineers who are responsible for designing schools and the project managers who work with the design teams. Volume 2 is organized by design disciplines, and it addresses specific design strategies for high performance schools. Volume 2's appendix contains data and guidelines on job-site specifications, information on calculating cost-effectiveness, a field-based thermal comfort standard for naturally ventilated buildings, the energy cost and indoor air quality performance of ventilation systems and controls, a lighting design supplement, and daylighting and fenestration design supplement. Volume 3 presents criteria which explicitly defines a high performance school. The criteria consist of required prerequisites and optional credits for which a school may earn points toward a goal of being a high performance school. (GR)

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ED 459 587

# High Performance Schools Best Practices Manual

## Volume I: Planning
## [and]
## Volume II: Design
## [and]
## Volume III: Criteria

Version 1.0

**Charles Eley, Editor**

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the
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# High Performance Schools

# Best Practices Manual

## VOLUME I

## PLANNING

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EF 005 928

# Volume I – Planning

## High Performance Schools Best Practices Manual

Version 1.0
March 1, 2001

A Project of:
the collaborative for high performance schools

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# Preface

## Background

This is a unique period in California history. The state, already educating 1 out of every 8 students in America, has seen historical enrollment rates four times higher than national averages. Hundreds of schools a year are being built to house the 100,000 new students per year moving into the system and to accommodate state-mandated class-size reductions. The current infrastructure is aging and over 30% of existing facilities are in need of major renovation. At the same time, California schools are spending nearly $450 million per year on energy[1] in a time of rising concern over energy supplies and tight school budgets. These figures illustrate an enormous opportunity for our state's school districts to build the next generation of school facilities that improve the learning environment while saving energy, resources, and money.

The goal of this Best Practices Manual is to create a new generation of high performance school facilities in California. The focus is on public schools and levels K-12, although many of the design principals apply to private schools and higher education facilities as well. High performance schools are healthy, comfortable, energy efficient, resource efficient, water efficient, safe, secure, adaptable, and easy to operate and maintain. They help school districts achieve higher test scores, retain quality teachers and staff, reduce operating cost, increase average daily attendance (ADA), reduce liability, while at the same time being friendly to the environment.

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[1] These costs are based on data prior to the California energy crisis, which begin during the winter of 2000-2001. During this period, wholesale energy costs by a factor of eight. Eventually, some or all of these costs will be passed on to schools and other utility customers.

## Best Practices Manual Organization

This Best Practices Manual is split into three volumes:

- Volume I addresses the needs of school districts, including superintendents, parents, teachers, school board members, administrators, and those persons in the school district that are responsible for facilities. These may include the Assistant Superintendent for Facilities (in large districts), buildings and grounds committees, energy managers, and new construction project managers. Volume I aims to describe *why* high performance schools are important, *what* components are involved in their design, and *how* to navigate the design and construction process to ensure that they are built.
- Volume II contains design guidelines for high performance schools. These are tailored for California climates and are written for the architects and engineers who are responsible for designing schools as well as the project managers who work with the design teams. Volume II is organized by design disciplines and addresses specific design strategies for high performance schools.
- Volume III is the CHPS Eligibility Criteria. These criteria are a flexible yardstick that precisely defines a high performance school so that it may qualify for supplemental funding, priority processing, and perhaps bonus points in the state funding procedure. School districts can also include the criteria in their educational specifications to assure that new facilities qualify as high performance.

The Best Practices Manual is supported by the CHPS website (www.chps.net), which contains research papers, support documents, databases and other information that support the Best Practices Manual.

## Who is CHPS

In November 1999, the Energy Commission called together Pacific Gas and Electric Company, San Diego Gas and Electric, and Southern California Edison to discuss the best way to improve the performance of California's schools. CHPS was formed out of this partnership and has grown to include a diverse range of government, utility, and non-profit organizations with a unifying goal: to improve the quality of education for California's children.

## Acknowledgements

A great number of people have contributed to the development of this manual. Charles Eley is the CHPS Administrator and served as the technical editor. Kathleen O'Brien and Jane Simmons (both of

### CHPS Stakeholders

California Department of Education (CDE)

Coalition for Adequate School Housing (CASH)

Division of the State Architect (DSA)

Office of Public School Construction (OPSC)

California Energy Commission (CEC)

California Integrated Waste Management Board (CIWMB)

Los Angeles Department of Water and Power (LADWP)

Pacific Gas and Electric Company (PG&E)

Sacramento Municipal Utility District (SMUD)

San Diego Gas and Electric (SDG&E)

Southern California Edison (SCE)

Southern California Gas Company (SoCalGas)

California Air Resources Board (CARB)

California Department of Health Services (DHS)

Natural Resources Defense Council (NRDC)

O'Brien and Company) are the primary author of the chapters on materials, site planning and general conditions. Jim Benya (Benya Lighting Design) and Tom Tolen (TMT Associates) wrote the lighting chapter. Barbara Erwine (Cascadia Conservation) and Lisa Heschong (Heschong Mahone Group) are authors of the daylighting chapter. Erik Kolderup, Joe Kastner, Anamika (all of Eley Associates), and Adam Wheeler (Control Group) wrote the HVAC and mechanical chapters. Randy Karels (Eley Associates) has worked with CHPS from the beginning and coordinated and edited Volumes I and III. Deane Evans of the Sustainable Buildings Industries Council (SBIC) developed the discussion guide and prepared much of the material on cross-cutting issues.

In addition to the primary authors, Anthony Bernheim (SMWM Architects), Lynn N. Simon (Simon & Associates), and Gary Mason (Wolfe Mason Associates) serve on the CHPS Technical Advisory Group and have helped develop and review content. John Guill (Quattrocchi / Kwok Architects), Dennis Dunston (HMC Architects), Kerry Parker (TMAD Engineers) and George Wiens (WLC Architects) serve on the Professional Advisory Group, a group of architects and engineers active in the design of California schools. Both advisory groups have made significant contributions to the document and to the overall direction of CHPS.

The CHPS stakeholders have not only made the Best Practices Manual possible through their funding, they have also contributed countless hours to reviewing the document and providing direction. Special thanks to Manuel Alvarez, Gregg Ander, Chuck Angyal, Duwayne Brooks, Richard Conrad, Don Cunningham, Julia Curtis, Ray Darby, Grant Duhon, Lisa Fabula, Chip Fox, Kathy Frevert, Randall Higa, Greg Golick, Tony Hesch, Jan Johnson, Oliver Kesting, Kathleen McElroy, Daryl Mills, Bill Orr, Dana Papke, Jim Parks, Robert Pernell, Tom Phillips, Richard Sheffield, Mike Sloss, Chip Smith, Lisa Stoddard, and Jed Waldman.

# Table of Contents

**Preface** ........ ii
  - Background ........ ii
  - Best Practices Manual Organization ........ iii
  - Who is CHPS ........ iii
  - Acknowledgements ........ iii
  - Table of Contents ........ v

**Volume I – Planning** ........ 1

**Understanding High Performance Schools** ........ 3
  - Benefits of a High Performance School ........ 4
  - Characteristics of a High Performance School ........ 5

**Health and Productivity Issues** ........ 8
  - Daylighting ........ 9
  - Indoor Air Quality ........ 12
  - Acoustics ........ 15
  - Commissioning ........ 15
  - Maintenance and Operations ........ 17
  - Relocatable Classrooms ........ 18

**Financing High Performance Schools** ........ 20
  - Life-Cycle Costing ........ 20
  - Reduced Operating Expenses ........ 21
  - Increased Funds ........ 22
  - Financial Incentive and Technical Assistance Programs ........ 23
  - Contacts ........ 24
  - Avoided Costs and Litigation Risk ........ 25

**Process Guide** ........ 27
  - Key Steps in the Process ........ 27
  - Building A School in California ........ 27
  - Process Steps ........ 29

**Discussion Guide** ........ 31
  - Programming and Goal Setting ........ 32
  - Selecting the A/E Team ........ 34
  - Site Analysis ........ 37
  - Schematic Design ........ 39
  - Design Development ........ 42
  - Construction Documents ........ 45
  - Bidding ........ 48
  - Construction Administration ........ 51

**Case Study 1: Daylit Classroom** ........ 54
  - Design Summary ........ 54
  - Construction Costs ........ 57
  - Lessons Learned ........ 57

**Case Study 2: The Capistrano Unified School District** ........ 60
  - The Skylighting System ........ 61
  - Electric Lighting ........ 62
  - Research Experience Pays Off ........ 62

**Case Study 3: Ross School** .......... **64**
Overview .......... 64
Thermal Comfort .......... 65
Lighting and Daylighting .......... 66
Indoor Air Quality .......... 67
Material Efficiency .......... 67
Site Issues .......... 68

# Volume I – Planning

California schools are facing multiple challenges: unprecedented student population growth, demands for improved student performance, constantly tight budgets, and thousands of school buildings in need of repair.

To meet these demands, districts will spend billions of dollars in the upcoming years to build or renovate hundreds of schools. How these schools are designed will affect the quality of the building, decades of operational expenses, and—most importantly—the health and productivity of generations of students and staff.

High performance school buildings—those that incorporate the very best of today's design strategies and building technologies—can simultaneously provide better learning environments for our children, cost less to operate, and help protect the environment.

Organized in 2000, the Collaborative for High Performance Schools (CHPS) aims to increase the performance of California schools by providing information, services, and incentive programs directly to school districts and designers. The goal of the CHPS stakeholders (see back cover) is to facilitate the design of high performance schools: learning environments that are energy efficient, healthy, comfortable, well lit, and contain the amenities needed for a quality education.

## By the numbers:

The California school system is the largest in the country. **One out of eight** K-12 students in America goes to school in California

Nearly **6.2 million** children, teachers, and administrators—1/5th of California's population—spends their day inside a school.

**100,000** new students enter the California school system every year.

**1/3rd** of California's K-12 students are housed in relocatables.

**1/3rd** of California's school facilities are in need of a major renovation.

Schools spend **$450 million** (nearly 3% of their total budgets) on energy. Between 20-40% (nearly **$150 million** statewide) could be saved by increasing the energy efficiency of building designs.

CHPS can help school districts and their design teams bring better performance into the classroom. Creating such schools is possible now. All that's needed is the vision, determination, and knowledge to do so.

This portion of the Best Practices Manual is written for school superintendents, school business officers, school facility planners, school board members, interested parents and others who are engaged in the process of planning new school facilities. It describes the benefits and characteristics of high performance schools, reviews the process of planning for, designing and getting approval for high performance schools, and describes available programs to supplement funding.

Volume II of the Manual has detailed guidelines for architects, engineers, school planners and contractors that lay out the specifics of how to design and build a high performance school. Volume III, the CHPS Eligibility Criteria, is a yardstick to measure progress toward achieving a high performance school. The criteria can be used by school districts to specify what they want and by designers to determine if they are achieving it.

# UNDERSTANDING HIGH PERFORMANCE SCHOOLS

High performance schools are facilities that improve the learning environment while saving energy, resources, and money. So what's the catch? Aren't these designs prohibitively expensive and time consuming? The short answer is no. The key is understanding the lifetime value of high performance schools and effectively managing priorities, time, and budget during the design and construction process. The detailed answer is woven throughout this Manual and addresses these important issues facing schools today:

- How will high performance schools help educate students? High performance design can have a positive effect on health and comfort, and design strategies such as daylighting have been shown to enhance student learning. Good indoor air quality is essential for teacher and student health. Good design also produces more comfortable environments with proper lighting, air temperature, humidity, and noise levels. This reduces distractions and creates environments where students and teachers can see clearly, hear accurately, and not feel too warm or too cold.
- Is high performance design cost effective? Yes. High performance design creates environments that are energy and resource efficient. These increased efficiencies save money on utility bills, and are so valuable that some organizations will provide building owners with funds to have them included in the design. Furthermore, healthier environments can bring money *into* the school by lowering absenteeism and increasing funding based on Average Daily Attendance. These financial, health, and productivity benefits are the result of integrated design: understanding how building elements affect one another to optimize the performance of the entire school.
- Do I have to choose between housing more students and high performance? No. Because a school facility must be able to house as many students as possible, building high performance schools at the expense of fewer classrooms is not an option. The key is to identify goals and budgets in advance and to verify that the designers and contractors explicitly understand your needs and their responsibilities. School construction budgets are tight, but cost-effective solutions can be found for nearly any budget.
- Will I have the time to do this? Yes. School design and construction timelines are short, but better design does not have to be a roadblock. As a district, you must identify your educational and high performance goals early and communicate them clearly with the design team. Your goals can then be integrated into the design from an early stage, and not require time- and money-intensive changes later in the process. The CHPS Eligibility Criteria is a convenient and flexible system for identifying your high performance goals.
- Do I need to be an expert in high performance building design? No. It's the architect's and engineer's role to make sure the design is as effective as possible. You must, however, identify and prioritize your goals, and hire designers with the appropriate skill sets. Without the luxuries of expansive timelines and budgets, every school design becomes a balanced system of trade-offs. Understanding the value of high performance design will be important as choices arise.

- Will high performance schools demand extensive maintenance? No. They do not require any more maintenance than traditional designs. High performance design does not imply using overly complicated, maintenance intensive systems. It is a design philosophy that integrates daylight, electric lighting, air conditioning and ventilation systems, site planning, materials, and controls to create the best facility for your budget. All schools, from traditional to high performance buildings, require regular maintenance to ensure they perform as designed. Health, comfort, and efficiency can all be compromised without adequate maintenance.

## Benefits of a High Performance School

High performance schools have advantages from the local classroom to the district office, including:

**Higher Test Scores.** A growing number of studies are confirming the relationship between a school's physical condition, especially its lighting and indoor air quality, and student performance. One recent study of school districts in California, Washington, and Colorado indicates a strong correlation between increased daylighting and improved student performance. In the California district, for example, students in classrooms with the most daylighting progressed 20% faster on math tests and 26% faster on reading tests in one year than those in classrooms with the least amount of daylight. The message is clear, and it confirms what teachers, students, and parents have known anecdotally for years: a better facility—one with appropriate acoustics, lighting, indoor air quality, and other high performance features—will enhance learning and may improve test results.

**Increased Average Daily Attendance (ADA).** A high performance school provides superior indoor air quality by controlling sources of contaminants, providing adequate ventilation, and preventing moisture accumulation. These tactics, designed to reduce sources of health problems and inhibit the spread of airborne infections, help keep pollutants, stale air, and mold growth out of the classroom. The result will be fewer sick days for students and teachers, especially those suffering from asthma or other respiratory problems. The majority of a school's operating budget is directly dependent on ADA, so even a small increase can significantly boost the operating budget.

**Reduced Operating Costs.** High performance schools are specifically designed—using life-cycle cost methods—to minimize the long-term costs of facility ownership. By using less energy and water than standard schools, overall operating costs are lower—most notably in times of rising and uncertain energy prices—and with good operation and maintenance will remain so for the life of the facility. School districts can save 20–40% on annual utility costs for new schools and 20–30% for renovated schools by applying high performance design concepts. Savings can be used to supplement other budgets, such as maintenance, computers, books, special education, more classrooms, and salaries.

**Increased Teacher Satisfaction and Retention.** High performance classrooms are designed to be pleasant and effective places to work. Visual and thermal comfort is high, acoustics are good, and the indoor air is fresh and clean. Such environments become positive factors in recruiting and retaining teachers and in improving their overall satisfaction with their work.

**Reduced Liability Exposure.** Because they are healthy and emphasize superior indoor environmental quality, high performance school buildings reduce a district's exposure to health-related problems, lawsuits, and loss of credibility. Remediation expenses for schools with indoor environment problems often reach a quarter of a million dollars, and legal costs can be much higher. Consequently, proactive measures that prevent problems are good investments.

**Reduced Environmental Impacts.** High performance school buildings are consciously designed to have low environmental impact. They are energy and water efficient. They use durable, non-toxic materials that are high in recycled content, and the buildings themselves can be recycled. They preserve pristine natural areas on their sites and restore damaged ones. And they use non-polluting, renewable energy to the greatest extent possible. As a consequence, high performance school buildings are good environmental citizens, and they are designed to stay that way for the entire life of the building.

These benefits are achievable only when districts establish high performance as a specific design goal from the very beginning, and fight for it over the course of the development process. A focus on student and teacher performance, coupled with a concern for the environment and a commitment to cost effectiveness, will help ensure that the effort is successful and that any school—no matter what its budget—achieves the highest performance level possible for its particular circumstances.

## Characteristics of a High Performance School

"High performance school" refers to the physical facility—the school building and its grounds. Good teachers and motivated students can overcome inadequate facilities and perform at a high level almost anywhere, but a well-designed facility can truly enhance performance and make education a more enjoyable and rewarding experience.

Creating one is not difficult, but it requires an integrated, "whole building" approach to the design process. Key systems and technologies must be considered together, from the beginning of the design process, and optimized based on their combined impact on the comfort and productivity of students and teachers.

Districts can use the CHPS Eligibility Criteria (Volume III of this manual) to facilitate and streamline the design process. The Criteria expand on these qualitative definitions to explicitly quantify what differentiates a high performance school from standard designs. Districts can use it to clearly communicate their design goals and verify the facility's final performance. Designers can use the system to set their timelines, budget and priorities. And both parties can use it to resolve trade-offs necessary to complete the project on time and within budget.

A high performance school is:

- **healthy**. Good indoor air quality is essential. It requires minimizing pollutant sources, and providing adequate ventilation and air filtration. The significant amount of time that students and teachers spend inside schools during their educational career, combined with children's increased susceptibility to indoor pollutants, underscores the importance of high indoor environmental quality.
- **thermally, visually and acoustically comfortable.** Thermal comfort means that teachers, students, and administrators should be neither hot nor cold as they teach, learn, and work. Visual comfort means that quality lighting makes visual tasks, such as reading and following classroom presentations, easier. The lighting for each room is "designed," not simply specified. Daylight and electric lights are integrated, and glare is minimized. Visual comfort also means providing a connection to the outdoors and visual stimulation through the use of windows at eye level to offer views. Acoustic comfort means teachers and students can hear one another easily. Noisy ventilation systems are eliminated, and the design minimizes the amount of disruptive outdoor and indoor noise affecting the classroom.
- **energy efficient.** Energy-efficient schools save money while conserving non-renewable energy resources and reducing atmospheric emissions of pollutants and greenhouse gases. Heating, ventilating, and air-conditioning (HVAC) systems use high efficiency equipment; are "right sized" for the estimated demands of the facility; and include controls that optimize system performance. The school's lighting system uses high efficiency products; optimizes the number of light fixtures in each room; incorporates control devices that ensure peak system performance; and successfully integrates electric lighting and daylighting strategies. The walls, floors, roofs, and windows of the school are as energy efficient as cost effectively possible. The building shell integrates and optimizes insulation levels, glazing, shading, thermal mass, air leakage, and light-colored exterior surfaces to minimize the use of the HVAC systems.
- **material efficient.** To the maximum extent possible, the school incorporates building materials that have been recycled or produced in a way that conserves raw materials. Such materials may be manufactured with a rapidly renewable resource or recycled content, are durable, or can be recycled or reused. In addition, the school has been designed and built in a manner that reduces waste and keeps re-usable or recyclable materials out of the landfill.
- **water efficient.** Water scarcity is a major problem in much of California. High performance schools are designed to use water efficiently, saving money while reducing the depletion of aquifers and river systems and minimizing the use of sewage treatment systems. The school uses as little off-site water as possible to meet its needs, controls and reduces water runoff from its site, and consumes fresh water as efficiently as possible.
- **easy to maintain and operate.** Building systems are simple and easy to use and maintain. Teachers have control over the temperature, airflow, acoustics, and lighting in their classrooms, and are trained how to most effectively use them.
- **commissioned.** The school operates the way it was designed and meets the district's needs. This happens through a formal commissioning process—a form of "systems check" for the facility. The process tests, verifies and fine-tunes the performance of key building systems so that they perform at the highest levels of efficiency and comfort, and then trains the staff to properly operate and maintain the systems.
- **an environmentally responsive site.** The site is recognized as an essential element of the school building's high performance features. To the extent possible, the school's

site conserves existing natural areas and restores damaged ones; minimizes stormwater runoff and controls erosion; and incorporates products and techniques that do not introduce pollutants or degradation to the project site or at the site of extraction, harvest, or production.

- **a teaching tool.** By incorporating important concepts such as energy, water, and material efficiency, schools can becomes tools to illustrate a wide spectrum of scientific, mathematical, and social issues. HVAC and lighting equipment and controls systems can be used to illustrate lessons on energy use and conservation, and daylighting systems can help students understand the daily and yearly movements of the sun.
- **safe and secure.** High performance does not compromise safety. Students and teachers feel safe anywhere in the building or on the grounds. A secure environment is created primarily by design: opportunities for natural surveillance are optimized; a sense of community is reinforced; and access is controlled. Security technology is used to enhance, rather than substitute for, the design features.
- **a community resource.** The most successful schools have a high level of parent and community involvement. This involvement can be enhanced if schools are designed for neighborhood meetings and other community functions.
- **stimulating architecture.** High performance schools should invoke a sense of pride and be considered a genuine asset for the community.

# HEALTH AND PRODUCTIVITY ISSUES

Because schools are complicated structures, high performance design covers a broad and diverse range of disciplines and choices. Building a high performance school does not mean buying and installing the latest, most expensive equipment. Rather, it is a design philosophy focused on choices that improve the learning environment and save resources. Some choices are essential and others are discretionary; it's important to keep the range of choices in perspective and focus on the key design issues.

Schools are unique buildings that every day house one-fifth of California's population: almost 6 million children and more than 200,000 teachers and support staff. There are few settings in which 20 to 30 people occupy such a small space or work on such a wide a range of activities as in a school classroom. Occupant density is approximately four times as great as a typical office building, and schools include many "special use" areas all within the same facility, such as laboratories, art studios, industrial shops, duplication facilities and gymnasiums.

Indoor environmental quality (IEQ) is a broad term that addresses the complete spectrum of indoor environmental factors: light quality, thermal comfort, indoor air quality (including humidity, odors and pollutants) and acoustics. Good IEQ is essential to the primary goal of school programs: to educate students.

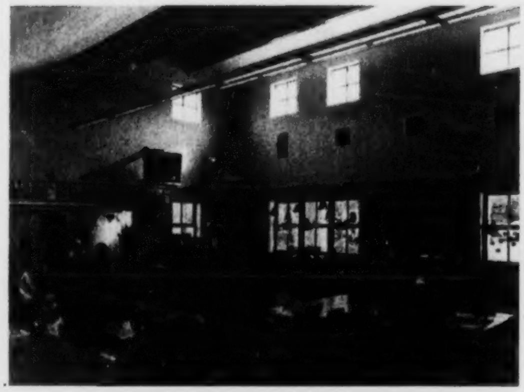
Learning is a dynamic, complicated process that can, and does, occur in all types of buildings and settings. Quantifying the influence of school facilities on learning is a longstanding and highly debated subject in the educational community. Research studies are complicated by the highly systemic nature of education and the range of social, pedagogical, psychological and environmental variables involved. However, there is now considerable empirical research explicitly connecting high performance building characteristics and student productivity.

Anecdotally, the argument is straightforward. Students in classrooms that are quiet, well-lighted, and properly ventilated with healthy air will learn faster because they are more comfortable, can see and hear better, and are less distracted. Poor lighting, poor acoustics, and poor indoor air quality are barriers to education. High performance schools remove these barriers, allowing teachers and students to work under the best possible conditions. The primary areas of concern affecting student health and productivity are: daylighting, indoor air quality, acoustics, commissioning, maintenance and modular classrooms

## Daylighting

It is well known that light has profound effects on humans, and new research has directly linked daylighting and increased learning in students.

In a 1999 study,[2] Heschong Mahone Group found a statistically compelling connection between daylighting and student performance. The study isolates daylighting as an illumination source, and separates illumination effects from other qualities associated with daylighting from windows.



*Santa Rosa, CA. Clerestories bathe this kindergarten classroom at Austin Creek Elementary School with daylight. Photo courtesy of Quattrocchi / Kwok Architects*

Student performance data from three elementary school districts was obtained and correlations investigated between the performance data and the amount of daylight provided within each student's classroom environment. Data from second through fifth grade students in elementary schools was used because there was extensive information available from highly standardized tests administered to these students, and because elementary school students are generally assigned to one teacher in one classroom for the school year. Thus, it was reasoned that if the physical environment does indeed have an effect on student performance, such a correlation could be established by looking at the performance of these elementary school students.

The research analyzed test score results for over 21,000 student records from the three districts, located in Orange County, California, Seattle, Washington, and Fort Collins, Colorado. The data sets included information about student demographic characteristics and participation in special school programs. Architectural plans, aerial photographs and maintenance records were reviewed and the research team visited a sample of the schools in each district to classify the daylighting conditions in over 2000 classrooms. Each classroom was assigned a series of codes on a simple 0–5 scale indicating the size and tint of its windows, the presence and type of any skylighting, and the overall amount of daylight expected.

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[2] The report, "Daylighting in Schools—An Investigation into the Relationship between Daylighting and Human Performance," was prepared for Pacific Gas & Electric Company and funded by California utility customers under the auspices of the California Public Utilities Commission. The research was undertaken by the Heschong Mahone Group and underwent a review process. The report was released in August 1999. Follow-up work is planned.

The daylighting conditions at the Capistrano school district were the most diverse, and the data from that district were also the most detailed. Thus Capistrano provided the most precise model. In this district, it was possible to study the change in student test scores over a school year. Controlling for about 40 other variables, it was found that students with the most daylighting in their classrooms progressed 20% faster on math tests and 26% faster on reading tests in one year than those with the least daylighting. Similarly, students with the largest window areas were found to progress 15% faster in math and 23% faster in reading than those with the smallest windows. And students that had a well-designed skylight in their room—one that diffused the daylight throughout the room, reduced glare, and allowed teachers to control the amount of daylight entering the room—also improved by 19–20% faster than those students without a skylight.

The research team also identified another window-related effect: students in classrooms where windows could be opened for natural ventilation were found to progress 7–8% faster than those with fixed windows, regardless of whether they also had air-conditioning. These effects were all observed with 99% statistical certainty.

The studies in Seattle and Fort Collins used the final scores on math and reading tests at the end of the school year, rather than the amount of change from the beginning of the year. In both of these districts the conclusions also found positive, and highly significant, effects from the daylighting. Students in classrooms with the most daylighting were found to have 7–18% higher scores than those with the least daylighting.

The three districts have different curriculum and teaching styles, different school building designs and very different climates. And yet the results of studies show consistently positive and highly significant effects. This consistency persuasively argues that there is a valid and predictable effect of daylighting on student performance.

However, the presence of daylight does not necessarily always translate to increased student productivity. Quality is a critically important factor in daylighting design. Classrooms

*Wake County, NC: "The daylit classrooms have increased the well being of the students and teachers and are at least partially responsible for our record high attendance rates. We are running about 3% ahead of the rest of the county in attendance. We stay around 98%."—Tom Benton, Principal. Photo courtesy Innovative Designs.*

*Salida, CA: Skylights do double duty in this 800-student, K-5 school. They provide high quality light to the classrooms and, at the same time, help vent air to the outside. In conjunction with operable windows, this allows natural ventilation to be used when the weather outside is temperate, saving on heating and cooling energy costs. "The skylights create an open, bright work environment. We just seem to have more room. Visitors say it sure is a pleasant place to come into." —Rick Bartkowski, Principal. Photo courtesy of Pacific Gas and Electric.*

with clear, non-diffused skylights are susceptible to patches of very bright light and glare which can become a detriment to learning. In fact, Heschong Mahone Group found that students with these types of skylights progressed up to 21% *more slowly* in reading.

Several other studies have drawn similar conclusions to the Heschong Mahone Group study:

- After a year of detailed observation of the behavior, hormone levels, and health of 90 eight-year old students, researchers in Sweden[3] found significant correlations between daylight levels, hormone levels, and student behavior. The students were split among four classrooms with different types of natural and artificial light. Their results indicated that "work in classrooms without daylight may upset the basic hormone pattern, and this in turn may influence the children's ability to concentrate or cooperate, and also eventually have an impact on annual body growth and sick leave."
- Researchers examining the effect of daylight in three North Carolina schools also found correlations between daylight and increased performance.[4] The study reports positive results for children moving to daylit schools: student performance increased up to 14%.

These benefits could be caused by a variety of effects including increased visibility due to higher illumination levels and light quality; improved student health, mood and behavior; reduced effects of daylight deprivation; and higher arousal levels.

Besides these positive educational effects, daylighting has a significant effect on utility expenses. About half of a school utility bill in California pays for lighting. Because of this, lighting systems are often identified for energy-conserving measures and programs. Daylighting saves energy, and therefore money, in two ways. Most obviously, lights that are off are not using energy. But lights that are off are also not generating heat, allowing the air conditioners to be downsized, work less and save energy.

As straightforward as these advantages appear, they do not just happen. The design team must work together using the principles of integrated design to maximize the effectiveness of daylighting systems, and the building occupants need to be educated about how the systems work. Lighting options range from no-cost and low-cost choices to sophisticated state of the art systems. It's important to communicate your goals clearly with the design team, and find a solution that fits your budget.

For more detailed information and best practice design strategies, see the Daylighting Chapter in Volume II of this Manual.

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[3] Kuller, R. and C. Lindsten. 1992. Health and behavior of children in classrooms with and without windows. *Journal of Environmental Psychology* 12: 305-317.

[4] Nicklas, M. and G. Bailey. 1997. Analysis of the performance of students in daylit schools. *Proceedings of the American Solar Energy Society*.

# Indoor Air Quality

Indoor air quality (IAQ) is vitally important to schools today—nothing less than the health of the students and staff is at stake. For years, news reports, scientific inquiries and educational efforts have brought attention to the symptoms, causes and solutions to indoor air quality problems.

*Boscawen, NH : This 420-student school is daylit and also utilizes 100% fresh outdoor air in a system that ensures superior air quality, while at the same time saving energy.*

*"It's light, it's bright and the use of space is so efficient for us, especially having come from a mid 1960's building. I've already sensed a calmness in the new building that is wonderful. It's an environment that's going to enhance our educational efforts. We expect to take off and do some remarkable things. The environment we're now living and working in will help us do that."—Jane Lacasse, Principal. Photo courtesy of H.L. Turner Group.*

Indoor pollutants such as chemical toxins and biological agents can create significant health risks and adverse learning conditions. Pollutants can affect a range of body systems, and affect health, learning, productivity and self-esteem. Health effects can be both transient (sick building syndrome) and long-term (building related illness, multiple chemical sensitivity), and may not affect all of classroom occupants in the same way. Symptoms range from mild discomfort and the perception of bothersome odors to severe illness and permanent injury. Health effects include increased rates of infectious diseases (influenza and the common cold, for example), eye and respiratory irritation, allergies and asthma, chronic sinusitis, headaches, and an array of other diseases. Environmental factors such as light quality, acoustics and overcrowding may also contribute to or create similar problems. Health problems are typically classified as follows:[5]

- Sick Building Syndrome (SBS). SBS describes a collection of symptoms experienced by building occupants that are generally short-term and may disappear after the individuals leave the building. The most common symptoms are sore throat, fatigue, lethargy, dizziness, lack of concentration, reparatory irritation, headaches, eye irritation, sinus congestion, dryness of the skin (face or hands), and other cold, influenza, and allergy type symptoms.
- Building-Related Illness (BRI). BRIs are more serious than SBS conditions and are clinically verifiable diseases that can be attributed to a specific source or pollutant within a building. Examples include cancer and Legionnaires' disease.
- Multiple chemical sensitivities (MCS). More research is needed to fully understand these complex illnesses. The initial symptoms of MCS are generally acquired during an identifiable exposure to specific VOCs. While these symptoms may be observed to affect more than one body organ system, they can recur and disappear in response to exposure to the stimuli. Exposure to low levels of chemicals of diverse structural classes can produce symptoms. However, no standard test of the organ system function explaining the symptoms is currently available.

Key to the concern about IAQ problems in schools is that children are believed to be much more vulnerable than adults to environmental contaminants and injury.[6] Relative to their size, both their breathing rates and metabolic rates are significantly greater than adults. Children will therefore breathe in and metabolize greater doses of airborne toxins than adults in the same environment. Because children's bodies are actively growing, they absorb and retain more of these toxins. Their defense mechanisms are less effective at preventing contaminants and infectious organisms from entering their bodies, and their immune systems are less able to respond when agents do enter.

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[5] United States Green Building Council. 1996. *Sustainable Building Technical Manual.* The following definitions are quoted from Chapter 13: "Indoor Air Quality" by Anthony Bernhiem. http://www.usgbc.org

Exposures to common molds and damp environments have been associated with childhood respiratory illnesses,[7] such as persistent wheezing, shortness of breath and bronchitis. Molds typically cause health problems when large quantities of air-borne spores are inhaled

*Roseville, CA: Despite its location in the central valley, all instructional spaces in the 500-student Maidu Elementary School are completely naturally ventilated. Classrooms, have operable windows. The library and media center rooms are surrounded by classrooms which limit their exterior exposure. However, operable windows in these spaces create a chimney effect to draw air from the classrooms and exhaust it through clerestories, while spreading natural light throughout the space. In 1998, this school won a Coalition for Adequate School Housing / American Institute of Architects Award of Merit. Photo courtesy Stafford King Wiese Architects.*

Across the country, student and staff populations have seen sharp increases in both the prevalence and severity of asthma.[8] Rates in urban areas have been especially high. This means an increasing number of students and staff is coming into the classroom with already highly sensitized respiratory systems.

In addition, IAQ has an indirect, yet profound, effect on learning. Inadequate ventilation leads to the buildup of carbon dioxide and other indoor pollutants, which are often associated with discomfort and the inability to concentrate. Exposures to volatile organic compounds (VOCs) and other indoor pollutants can cause a range of acute symptoms at relatively low concentrations; eye and respiratory irritation are the most common complaint. These indoor contaminants can also cause headaches, mental confusion, behavioral problems, and fatigue, all of which diminish students' ability to concentrate or assimilate information. Among asthmatics, the increased need for medication (often with sedating side effects), exacerbations of asthma attacks, and related absences from school further undermine education in affected classrooms.

A recent report from Lawrence Berkeley National Laboratories[9] summarized the history of school investigations initiated by health symptoms and/or environmental complaints. They

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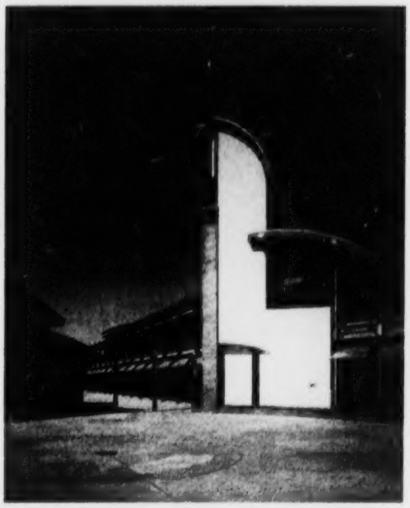
6 National Institute of Environmental Health Sciences. 1999. Children's Environmental Health and Disease Prevention Research. *Environmental Health Perspective* 107 (Supplement 3, June).

7 Spengler, J. et al. 1994. *Indoor Air* 4:72-82. Verhoeff, A.P. et al. 1995. *American Journal of Epidemiology* 141:103-110.

8 Monnino, D.M. et al. 1998. Surveyance for asthma—United States, 1960-1995. Centers for Disease Control & Prevention, *MMW* 47(SS No. 1, April 24).

9 Daisey, J.M. and W.J. Angell. 1998. A survey and critical review of the literature on indoor air quality. Ventilation and Health Symptoms in Schools, Indoor Environment Program, Lawrence Berkeley National

reviewed 53 Health Hazard Evaluation Reports for 1981–94 from the National Institute for Occupational Safety and Health (NIOSH), and 35 California indoor air quality investigations for 1988–96. They found that the frequency of recurring symptoms, such as headaches, fatigue, memory problems, eye irritation, and cough in schools were there had been complaints, was markedly increased relative to schools without complaints. Similar symptoms in office buildings have been associated with reduced worker productivity, suggesting that school IEQ problems can be severe and persistent enough to affect the learning ability of students individually or as a group.



*San Diego, CA. This addition of 24 classrooms to Wangenheim Middle School was designed to optimize energy efficiency and indoor comfort using passive systems. The site and envelope design of the new one- and two-story buildings promote cross ventilation and daylighting through use of operable windows, clerestories, light shelves, and interior reflective surfaces. Appropriately sized shading devices protect the interiors from unwanted solar gain.*

*"On bright days, we operate the classrooms frequently without any of the lights on." "We like the cross ventilation. These classrooms are much more comfortable than the others. On hot days, the classrooms are at least ten degrees cooler than the portables."- Teachers at Wangenheim Middle School. Photo courtesy Platt/Whitelaw Architects. Hewitt Garrison, photographer.*

School districts have the power to control their indoor air quality. Because of the diverse range of pollutant sources and the potentially high costs of corrective actions, schools should focus on prevention. Many no-cost and low-cost approaches are available to prevent problems. The key elements are:

- Maintenance. Maintenance practices are crucial to preventing indoor air quality problems. Regularly inspecting and maintaining HVAC systems ensures adequate ventilation rates; cleaning up spills and moisture avoids mold and microbial growth; regular carpet and floor cleanings minimize surface dust; and integrated pest management techniques minimize the use of toxic materials.
- Proper Siting. This minimizes exterior sources of pollution and keeps the ventilation system's air intakes away from pollutant sources such as parking lots or building exhaust vents.
- Appropriate materials. Pollutants can be eliminated at the source by using low-emitting, non-toxic building materials. Pressed wood products such as particle board, carpets, paints, adhesives, furniture, and wall-coverings have all traditionally contained toxins that contribute to indoor air quality problems. In today's market, low-emitting alternatives are available for most building and finishing materials.
- Effectively Designed and Commissioned Heating, Ventilation, and Air-Conditioning (HVAC). Building codes specify minimum ventilation rates for schools. Ventilation is critical to removing indoor pollutants from the classroom. Unfortunately, many schools never meet these guidelines. A 1995 California Energy Commission report found that schools consistently had sub-standard ventilation rates, and 1 in 3 classrooms were ventilated at less than half the legal minimums.

The Technical Guidelines (Volume II) and the High Performance School Criteria (Volume III) of this Manual cover all of the design issues relevant to ensuring superior indoor air

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Laboratory, Berkeley, CA. Report No. LBNL-41517. Prepared for the Office of Environmental Health Hazard Assessment, March 1998.

quality. See also Chapter 13 of the *Sustainable Building Technical Manual* published by the United States Green Building Council.

## Acoustics

When noise levels in the classroom are too high, students and teachers lose the ability to intelligibly understand each other. Typical sources of noise are outdoor sounds (traffic, airplanes, etc.), loud air-conditioning and ventilation systems, and internal noise from other school spaces. The teacher's and student's inability to hear one another directly affects student performance. Teachers must sometimes resort to shutting off ventilation systems because they are too loud, which can have the unfortunate side effects of reducing indoor air quality and thermal comfort.

Students are particularly susceptible to the ill effects of background noise. Age, instances of hearing loss, lack of language proficiency, and individual hearing preferences can all affect how well a given student can hear in the classroom. Approximately 15% of children are estimated to have a slight hearing loss, and investigations of school records have linked hearing losses with lack of progression through school. Typically, children do not fully develop the ability to sort sounds from background noise until they are teenagers.

Recognition of the widespread acoustic problems in the United States are spurring developments of a national minimum acoustical standard for classrooms that may be enforced under the auspices of the Americans with Disabilities Act. Typical low first-cost air-conditioning systems used throughout California do not meet the recommended levels for background noise. Location of HVAC equipment, duct design and internal surface choices all contribute to the overall acoustic performance of the space.

Because of the significant, direct effects of improper acoustical design, acoustical recommendations are included in both the Technical Design Guidelines in Volume II and the CHPS Eligibility Criteria in Volume III.

## Commissioning

No matter how carefully a school is designed, if the building materials, equipment and systems weren't installed properly or aren't operating as intended, the health, productivity and other benefits of high performance design will not be achieved. Building commissioning is a quality assurance program that is intended to show that the building is constructed and performs as designed. It's a powerful tool because it can indicate if the designers and contractors have done what you hired them to do. If commissioning reveals problems with design or construction, the district then has the authority to make the responsible parties fix the problems up front instead of dealing with maintenance problems or poor performance down the road.

In many ways, commissioning is similar to a "test run" or "systems check." It tests, verifies, and fine-tunes the performance of key building systems so that the highest levels of performance are achieved. Correctly implemented, commissioning should improve the building delivery process, increase systems reliability, improve energy performance, ensure good indoor environmental quality, and improve operation and maintenance of the facility.

All building systems can be commissioned, however, mechanical, electrical, and life safety systems are most important. The important components of commissioning are:

- *Installation checks.* Check installed equipment to ensure that all associated equipment and accessories are in place.
- *Operational checks.* Verify and document that systems are performing as expected, and that all sensors and other system control devices are properly calibrated.
- *Documentation.* Ensure that all required documentation has been provided, such as a statement of the design intent and operating protocols for all building systems.
- *O&M manuals and training.* Prepare comprehensive operation and maintenance (O&M) manuals, coupled with training of building operations staff.
- *Ongoing monitoring.* Conduct ongoing monitoring after the school is occupied to ensure that equipment and systems continue to perform according to design intent.

Properly implemented, commissioning will ensure that a new school starts its life at the highest performance level possible. Building commissioning is a newly evolving practice and is becoming more widely used. It's therefore important that commissioning responsibilities—particularly who will bear the cost of correcting conditions that do not meet specifications—are clearly spelled out in the beginning of the design process.

Commissioning can take place for one building system or for the entire facility; however, the more comprehensive the commissioning, the greater the impact on school performance. Whichever level of commissioning chosen, the following procedures should be implemented:

- engage a commissioning agent (the person responsible for implementing the commissioning plan) during the schematic design phase or earlier. The agent may be a member of the design team, an independent contractor, or a member of the school district staff;
- collect and review documentation on the design intent;
- make sure commissioning requirements are included in the construction documents;
- write a commissioning plan and use it throughout design and construction;
- verify installation and functional performance of systems;
- document results and develop a commissioning report;

For more information on commissioning, see the Overview section in Volume II of this Manual. Additional commissioning information is provided with each guideline in Volume II.

## Maintenance and Operations

Effective maintenance and operations procedures are fundamentally important to sustaining the performance of all building systems. Student health and productivity can be affected when building systems fail to operate as designed. Sub-standard maintenance or incorrect operation of building systems usually results from a combination of factors. First, maintenance budgets are often the first to be reduced or eliminated when money becomes tight. Second, designers and contractors typically provide the building staff minimal or no training out how the building systems are supposed to operate or be maintained. Finally, schools eventually lose their institutional knowledge of the building systems because of staff turnover and lack of communication.

High performance schools are maintenance friendly. Building systems are easy to maintain, and reduced operating costs from energy-efficient design frees money that could be directed to support maintenance efforts.

Additionally, high performance design urges the clear identification of roles, responsibilities, and budget to ensure that important maintenance information is transferred to the building occupants and not lost in the rush to occupy the building after construction is completed. One example would be the creation of a brief *classroom operation manual* for teachers. This could be developed by the designers and distributed to the staff to teach them the how to work with the building systems to maximize their comfort. Particular issues to be explained would be how to use the lighting system, HVAC controls, and windows; how to avoid glare when using computers; the best methods for controlling temperature; how to prepare the room for A/V presentations; or any other subjects that are important to the teachers and staff.

An effective maintenance plan should include the following items:

- educate the staff on the value of maintenance, and how a properly functioning facility will help them educate their students;
- establish a budget for maintenance;
- hire qualified staff or contractors to perform tasks;
- develop a preventative maintenance plan, including schedules for periodic maintenance checks;
- develop a predictive maintenance program to prevent problems from occurring;
- use a work order system to track work orders, maintenance performed, and costs for each piece of equipment;
- ensure that the maintenance staff has proper Operation and Maintenance manuals;
- ensure availability of recommended spare parts in the warehouse;
- provide training to the maintenance staff.

## Relocatable Classrooms

Portable—or "relocatable"—classrooms have been a feature of California schools for years. From a district's perspective, the two advantages of relocatable classrooms are low initial cost and short time between specification and occupancy. They are intended to provide flexibility to school districts, enabling quick response to demographic changes and providing the ability to be moved from one school to another as demographics change. In reality, relocatable classrooms are seldom moved and become permanent fixtures of the school.

Recent surges in student population combined with legislated Class Size Reduction (CSR) efforts fueled an explosion in the use of relocatable classrooms throughout the state. By the end of the second year of the CSR program, over 98% of districts had participated. Consequently, the number of relocatable classrooms has increased over 80% between 1991 and 1998, and they are now used to house more than one-third of all California students. Concerns about the healthfulness of relocatable classrooms have arisen. Teachers in the new units frequently complain of chemical odors. In older units, odor problems were often associated with moldy classroom carpets. Both new and older units are often subject to complaints about poor ventilation. An informal survey was recently conducted by the Coalition for Adequate School Housing (CASH) on indoor air quality problems in classrooms.[10] Of the 144 districts reporting, almost 40% had received complaints regarding indoor air quality in relocatable classrooms. In several districts, relocatable classrooms were closed temporarily for testing or corrective action.

The effects of poor indoor air quality in relocatable classrooms are no different from those in permanent classrooms. All school buildings use similar construction and furnishing materials, so the types of chemicals present in indoor air are not likely to be different for relocatable versus permanent classrooms. However, pressed-wood products (often with high concentrations of formaldehyde) are used more in the factory-built relocatable units than in buildings constructed on-site. As result, levels of airborne chemicals may be higher in new relocatable classrooms, especially if ventilation is reduced.

The most common problems with relocatable classrooms across the state include:

- Poorly functioning HVAC systems that provide minimal ventilation of outside air
- Poor acoustics from loud ventilation systems
- Chemical off-gassing from pressed wood and other high-emission materials, compounded by quick occupation after construction or installation of carpets
- Water encroachment and mold growth
- Site pollution from nearby parking lots or loading areas

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[10] Coalition for Adequate School Housing. 1999. *Survey of Reported Instances of Problems with Indoor Air Quality in Classrooms*. (July 26) Sacramento, CA. Coalition for Adequate School Housing. Tel: (916) 448-8577.

The solutions to these problems are no different than the recommendations for improving indoor air quality in permanent structures.

Although relocatables are the lowest cost option for housing students, they range in quality. Care should be taken during specification and selection to ensure that the health of the students and the district money are not compromised on inexpensive, low quality designs. When districts specify a relocatable design, they typically create a term contract that other districts can use to purchase the same (or slightly different) design. This practice (often called "piggy-backing") can save a district valuable time and money on specifications and approvals.

PG&E's Premium Efficiency Relocatable Classroom (PERC) Program provides recommendations for a variety of low- and no cost changes that will improve the performance of relocatables. Contact Oliver Kesting at 415-973-0012 for more information.

Recognizing that relocatable classrooms are often used as permanent structures, Southern California Edison created its "Rethinking the Portable Classroom" program to re-design the standard relocatable building. The project, which involved numerous parties with an interest in relocatable classrooms, led to the development of a prototype designed to be a cost-effective alternative to site-built projects. This prototype has been built and will be tested for one year. The prototype design meets all state transportation codes, has a more permanent appearance than conventional relocatable buildings, and is flexible enough to be used at a variety of sites. In addition, the prototype is daylit, is configured to optimize teaching space while providing storage space, and is designed to improve indoor air quality. It is projected to reduce annual energy costs by 35% over typical designs. For additional information, contact the Edison Customer Technology Application Center (CTAC) at 800-336-2822.

# FINANCING HIGH PERFORMANCE SCHOOLS

High performance schools are cost effective for a number of reasons. For example, they can:

- Bring more money to the school by increasing average daily attendance,
- Keep more money in the school by significantly reducing utility bills, and
- Take advantage of currently available incentive programs.

When the avoided costs of workers' compensation claims and litigation are also considered, high performance schools become an even wiser business choice for school districts. Discussed below are issues related to financing high performance schools, including life-cycle costing, reduced operating expenses, increased funds, financial incentive and technical assistance programs, avoided costs and reduced litigation risks.

## Life-Cycle Costing

School facilities are investments. State government and local communities spend billions of dollars per year on new facilities for current and future generations of students. Unfortunately, the institutional separation of operational and construction budgets can create schools that are economically, environmentally and educationally poor investments.

Many high performance measures can be incorporated into a school design without increasing first costs, but additional investments can increase the health and efficiency of the school even further. However, if a conventional financing methodology is used, design measures that save money in the long-term may be rejected because they cost more initially.

Life cycle costing is a means to calculate and compare different designs to identify which is the best investment. Districts can use it to assess the total cost of ownership for a facility over time. All of the building expenses that can be calculated are included in the analysis; including initial costs (design and construction), operating costs (energy, water, other utilities and personnel), and maintenance, repair and replacement costs. The values are adjusted for the time-value of money to represent the true value of the investment. Predicted costs for alternative design approaches can then be compared, allowing the district to

*San Diego Unified has taken steps to ensure that their new buildings are the most cost-effective options for all of their new construction projects. Language included to ensure high performance schools includes:*

*"If the scope of the project includes mechanical work, the Architect shall require the Mechanical Engineer to provide a heating, ventilation, and air conditioning (HVAC) life cycle analysis.* ***The Engineer shall submit three HVAC alternatives for conditioned buildings for review by the District. Each alternative shall include initial and life-cycling costs.*** *The selected alternative for the conditioned building(s) shall be modeled by using the most recent edition of Energy Pro or equivalent modeling software as approved by the District.* ***The program results should demonstrate the overall energy efficiency of the building(s) on a performance basis.*** *Modernization projects not suitable for modeling shall include prescriptive Title 24 calculations.* ***The Architect will participate in Utilities' rebate/reimbursement programs as directed by the District."***

select the design that provides the lowest overall cost of ownership consistent with the desired quality level.

The true cost of a school includes much more than the cost to design and build it. The long-term costs of operating and maintaining the facility must also be included. Only by evaluating all three of these factors can a community understand how much a new school really "costs". And only by looking at all three factors simultaneously can the impacts of specific design approaches, especially those that result in better long-term performance, be evaluated. High performance windows, for example, may cost more upfront but may result in energy savings that pay for the extra costs in a few years and then continue to save money for the school for years to come. Life cycle cost analysis is the key to making these kinds of comparisons and to creating new schools with the lowest long-term costs of ownership. Note, however, that life cycle costing will only address some of the benefits of high performance design. Many benefits, such as improved health and test scores, are valuable, but difficult to quantify monetarily. A more detailed description of life cycle cost methods and techniques is included in the electronic Appendix[11] "Calculating Cost Effectiveness."

## Reduced Operating Expenses

High performance schools cost less to operate. School districts spend less for electricity, gas, water, maintenance and other ongoing facility operating costs, enabling more money to be spent for salaries, books, teaching supplies and other items with a more direct link to the true mission of schools: educating students.

How much savings can be expected? School districts can save 30–40% on annual utility costs for new schools and 20–30% for renovated schools[12] by applying high performance design and sustainability concepts. The potential for savings is greater in new schools because it's possible to "design out" inefficiencies from the outset, thereby saving money year after year.

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[11] The electronic Appendix is available at http://www.eley.com/chps/manual, and on the CHPS Best Practices Manual CD-ROM.

[12] These savings are achievable when compared to the stringency of current standards. The stringency of the California energy standards is regularly increased. These percentages will therefore change.

The California Energy Commission estimates that the average cost of energy, per student, is $126. Expenditures for electricity and natural gas typically run 2.2% to 2.7% of the total schools budget. High performance design solutions could yield savings of up to $50 per year with aggressive designs. Furthermore, these savings continue to reap savings as long as they are used as designed.

Integrated design is the key to savings of this magnitude. From the beginning of the design process, each of the building elements (windows, walls, building materials, air-conditioning, landscaping, etc) is considered part of an integrated system of interacting components. Choices in one area often affect other building systems; integrated design leverages these interactions to maximize the overall building performance.

*San Diego, CA. San Diego Gas and Electric assisted San Diego Unified to find the most cost effective and energy efficient design solutions for Garfield Elementary. The final design saves $100,000 annually. High performance measures include, external shading, highly insulated roofing, high performance windows, T-8 lighting, occupancy sensors, daylighting controls in selected spaces, skylights, and other measures. Photo courtesy of San Diego Unified School District.*

## Increased Funds

Investing in high performance measures can bring monetary returns to the school district. District funds come from a variety of state, federal and local sources, and every district has a unique blend of sources. In general, a district's funding can be divided into three components:

- General Purpose Funds are calculated by multiplying a school's Average Daily Attendance by its Revenue Limit. Current revenue limits for the 2000-2001 school year are $4,306, $5,175 and $4,485 for elementary, high school, and unified schools, respectively.
- Categorical Aid covers a wide array of programs from special education to instructional materials. The application process and funding amounts vary depending on the programs. Depending on the district, categorical aid can range from small amounts to almost one-third of their total budget.
- Miscellaneous funds comprise the small remaining amount. Typical sources are the lottery and various local sources.

High performance schools can increase school funding by increasing average daily attendance, through reduced illnesses and more user satisfaction. Because the revenue limits range from $4,300 to $5,175, even small changes in attendance can significantly affect a school's bottom line. Recent changes in the funding mechanism that exclude excused absences from the Average Daily Attendance calculation further increase the financial necessity of keeping as many students in class as possible.

For example, assume that a 500-student elementary school invests $4.00 per square foot on high performance lighting and air-conditioning improvements that will improve the indoor environment quality. Based on the $4,300 revenue limit, an increase in Average Daily Attendance of 1.75% would pay back all of the investments in only two years.[13] And this doesn't begin to take into effect any utility savings from energy efficiency improvements.

> *"I have noticed a big difference in my health since we've been in the new school. I had a lot of absenteeism—in fact I was hospitalized in the old building. In the new school, I won't say that I'm cured of asthma—I still have it and I still have allergies—but I really don't have many problems at all and I'm feeling great."—Teacher at a new school in New Hampshire using the Advantage Classroom™ design concept.*

Although many studies have correlated characteristics of the indoor environment to changes in student health, behavior and performance, estimating the degree to which absenteeism might be reduced by a given investment in high performance design is unknown. Ongoing research may eventually provide an answer, but for now it's reasonable to assume that investing in high indoor environmental may decrease absenteeism.

## Financial Incentive and Technical Assistance Programs

Several programs are currently available to financially and technically assist districts and designers in creating high performance schools.

The **Savings By Design** program promotes energy-efficient design in new construction and renovation projects with financial incentives and technical resources for designers, contractors, and building owners. The program is funded by California utility ratepayers and is administered by Pacific Gas and Electric Company, San Diego Gas & Electric, Southern California Edison, and Southern California Gas Company under the auspices of the California Public Utilities Commission. It is available for any school district within these utilities' service territories. The financial performance-based incentives increase with the energy efficiency of the design and can be a significant source of additional funds.

In addition, Savings By Design offers technical assistance and project-specific design assistance to the school design community. Savings By Design sponsors training and continuing education in integrated school design practice (for example, daylighting systems, proper HVAC sizing, integrating internal loads from other end uses, proper HVAC installation, and building system modeling). More information is available at www.savingsbydesign.com.

The California Energy Commission's **Bright Schools** program offers a full suite of programs to schools considering high performance design strategies in new and existing buildings. School districts can use the program to evaluate potential areas for energy and resource savings and prioritize their needs. The services are typically provided at little or no cost to districts.

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[13] Assumes 960 square feet per classroom and 20 classrooms in the school.

On new construction projects, the Bright Schools program provides a variety of services, including design consultation, cost-effectiveness calculations, development of specifications, help in selecting the design team, review of construction documents, and complete value engineering of specific efficiency measures.

Bright Schools also provides comprehensive services for energy renovations. The particular services are determined by the program and the district and may include energy audits, feasibility studies, design review, equipment specifications, and contractor selection and installation assistance. In addition, schools can take advantage of a loan program to help finance the required district match of renovation projects. More information is available at www.energy.ca.gov/efficiency/brightschools/info.html

**Standard Performance Contracting** (SPC) is a renovation incentive program funded by utility ratepayers and administered by Pacific Gas and Electric Company, San Diego Gas & Electric, and Southern California Edison under the auspices of the California Public Utilities Commission. It offers schools additional financial support for implementing energy efficiency improvements to existing facilities.

Under the program, Energy Efficiency Service Providers (EESPs) provide information and energy audit services to analyze energy saving opportunities in existing school buildings. If energy-efficiency projects are identified, the utility will provide funds to help finance the project in exchange for the energy savings. The utility can make a contract with either the school district or the EESP, depending on how the district wants to manage the project. Often, school districts will contract with an EESP for project development, management, and construction, and the EESP will contract with the utility. Either way, the school district receives an improved facility at a lower cost.

**Energy Design Resources**, is a program to develop and disseminate design tools and resources that help elevate energy efficiency in new schools to a higher priority. It is funded by utility ratepayers and administered by Pacific Gas and Electric Company, San Diego Gas & Electric, and Southern California Edison under the auspices of the California Public Utilities Commission, Resources include both informational publications such as design briefs and in-depth handbooks on the latest

## Contacts

**CHPS**

www.chps.net
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877–642–CHPS

**Savings By Design**

www.savingsbydesign.com

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Contact local representative or call:
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**Municipal Utility Programs**

Sacramento Municipal Utility District
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L.A. Dept. of Water and Power
800–GREEN LA

energy technologies, and software design tools to guide design decision-making. All resources are available for download at the Energy Design Resources website at www.energydesignresources.com.

The Sacramento Municipal Utility District and the Los Angeles Department of Water and Power have specific **incentive programs** for efficient air-conditioning and lighting systems. Schools in their territories should contact them directly for more information.

## Avoided Costs and Litigation Risk

The considerable costs of poor school IEQ are borne by students, staff, parents and the local community. In the school populations, the costs include poor health, reduced learning effectiveness, and increased frustration when IEQ problems become unmanageable. These costs are difficult to quantify. More easily counted are the strained budgets and staff resources expended by districts for facility repairs due to insufficient maintenance, community relations damage control, litigation, and workers' compensation claims. In addressing such problems, schools must use resources that would otherwise be available for educational and other programs.

Poor school IEQ can cause both short-term (reversible) and long-term (chronic) effects in students and staff. Overcrowded, poorly ventilated classrooms contribute substantially to the spread of infectious diseases, such as colds and influenza. Poorly maintained carpets, dirty air ducts, and water-damaged materials are prime breeding grounds for a plethora of substances that can trigger asthma attacks, sensitize allergy-prone individuals, and cause sinus and respiratory infections. Asthma is one of the environmentally triggered diseases acquired during childhood that may be carried well into the adult years. Other chronic diseases include irreversible lung and respiratory illnesses that result from chronic irritation by airborne chemical and/or biological contaminants. The economic costs of these long-term, possibly lifelong, diseases are substantial; the costs in terms of quality of life are more profound, and certainly difficult to measure.

One of the ramifications of school building neglect and its consequent adverse effects on IEQ is the potential for litigation from students, parents and staff. Crisis-stage IEQ problems can be extremely costly, may lead to litigation, and can be detrimental to long-term relations among school administrators, staff, parents, students and public agencies. The fiscal, political and social costs of addressing a crisis situation are often far larger than anticipated. Schools may close temporarily when a formerly manageable problem becomes a financial, logistic, and emotional crisis. Besides the costs of conducting emergency repairs, a school closing requires alternative space and making up missed classes. Reopening schools that have been closed is also a difficult process, due to the logistics of inspections, the uncertainties of authority, and residual fears. Workers' compensation claims by school staff are another financial cost to districts when IEQ complaints escalate.

The threat of increasing IEQ problems, recognition of adverse health effects from indoor air exposures, and the litigious nature of societal interactions warn that poor IEQ in California schools can threaten the financial stability of local school districts. A number of lawsuits have been filed against California school districts. For example, after complaints, investigations, and legal actions spanning more than three years, a student received a cash settlement for damages from "contaminated air" in his junior high school classroom. At the same time a third of the school staff filed workers' compensation claims for respiratory and other health problems. In other states, lawsuits have been settled for millions of dollars. In a school district in Washington, D.C., leaky school roofs and other IEQ problems prompted a judge to order closed 21 school buildings due to the resultant potential fire hazard. For each incident that makes the evening news or is adjudicated in court, there are many less publicized cases occurring in other districts.

Building a high performance school helps protect districts from IEQ problems by designing out potential problems and verifying and documenting the facility's health.

# PROCESS GUIDE

## Key Steps in the Process

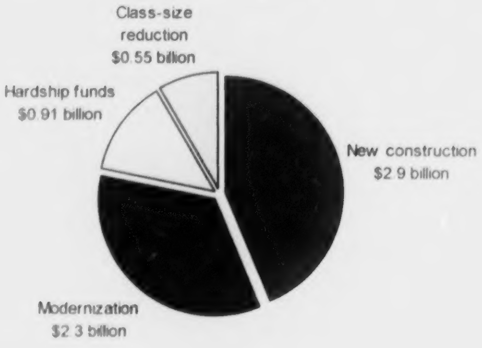
Whether building a new school or renovating an existing structure, there are nine key elements to creating a high performance school:

- Set high performance goals early and include them in your educational specifications.
- Minimize the impact of the site.
- Select design team with necessary qualifications and experience with high performance design.
- Communicate Goals to Designers.
- Pursue Integrated Design.
- Communicate goals to contractors.
- Monitor Construction.
- Verify Goals.
- Train Occupants

## Building A School in California

In 1998, Proposition 1A reorganized the school design and approval process under a program called the School Facilities Program (SFP). All school districts seeking state money for new construction, modernization, or class size reduction funds must participate in SFP. Overall project funding is a combination of state and local money; the state will support 50% of new construction costs and 80% of modernization costs. The California legislature appropriated just under $9.2 billion in bonds to fund these programs. The majority of these funds ($6.7 billion) were allocated to California's K–12 public school system, and split between new construction, modernization, hardship, and class-size reduction as shown at right.

**K-12 Bond Allocation**



### Primary Players

There are five primary players in the California Proposition 1A process:

- **The School Districts** are solely responsible for the origination and management of the entire construction process. They must secure local funding, manage the designers and contractors, and are responsible for any changes required for approval and release of the funding.
- **The State Allocation Board (SAB)** distributes all state funding for new construction and modernization of public schools. Funds are distributed quarterly based on a priority points system.
- **The Office of Public School Construction (OPSC)** is staff to the SAB, and as such, develops programs and policies that carry out the SFP's mandates. Duties include processing applications and creating agendas for the SAB. OSPC is a division of the Department of General Services (DGS).
- **The California Department of Education, School Facilities Planning Division (SFPD)** determines whether the site and plans are safe for the children, and that the facility supports the educational specifications of the district and state. The SFPD must approve the site and plans, and maintains the closest relationship with the district during the process. SFPD is a branch of the California Department of Education (CDE). They publish a range of materials to assist districts through the planning and design process, including *Guide to School Site development* (2000), *School Site Selection and Approval Guide* (2000), *Educational Specifications* (1997), and *The Form of Reform* (1997). In addition, the have recently updated the section of the *Title Five California Code of Regulations* titled "School Facilities Construction". All school construction must comply with the minimum standards and regulations outlined in Title 5. (Subjects include: minimum standards, master plan requirements, minimum distances from power lines and airports, hazardous waste requirements, minimum classroom sizes, waste disposal, surface drainage, traffic and pedestrian safety requirements, etc.)
- **The School Facilities Planning Division (SFPD)** determines whether the site and plans are safe for the children, and that the facility supports the educational specifications of the district and state. The SFPD must approve the site and plans, and maintains the closest relationship with the district during the process. SFPD is a branch of the California Department of Education (CDE)
- **The Division of the State Architect (DSA)** approves the plans based on structural safety, fire safety, and accessibility. The State Architect is also charged with checking for compliance with the state energy efficiency requirements. DSA is a division of the Department of General Services (DGS). The Construction Inspector of Record (IOR) is approved for each school project by the DSA.

The SFP overhauled the way public schools are financed and the roles of the government agencies involved. Basically, SFP streamlined funding by giving districts a flat grant for new construction and modernization projects. The amount of state funding depends on the number and grade level of the students served by the new facility. The grants are processed by the OPSC, approved by the SAB, and intended to be the entire contribution of the state. Under the SFP, districts have greater freedom in managing their projects, but also bear more responsibility. Any cost overruns are the responsibility of the district, and conversely, the district can keep any savings produced by cost-efficient construction.

School districts may also choose to fund entire school construction using their own local bonding authority and proceed without the involvement of OPSC or CDE/SFPD

## Process Steps

The table below outlines the general process of school construction and the key actions necessary to ensure that a high performance school is specified, designed, and constructed.

| | *Standard Process* | *Crucial High Performance Actions* |
|---|---|---|
| 1. **Programing and Goal Setting** | **Determine Need.** District conducts long range planning: investigates population trends and current facilities to determine its long-term and current facility needs.<br>**Educational Specifications.** The educational specification is the primary tool to describe the school's educational goals, and set architectural guidelines to meet those goals.<br>They may include information on the specific spaces to be included in the project, the area required for each space, the relationships between the spaces, and details on the mechanical, electrical, and technological systems. Information on the educational programs, including the curriculum and the methodology in which the curriculum is delivered, may also be included.<br>The CDE highly recommends creating educational specifications. They consider the educational specification crucial to the development of high quality schools, and use it as a tool to educate the districts on relevant issues. | **Set high performance goals early and include them in district or educational specifications.**<br>Including the goals in specifications is a crucial step. It becomes important and valuable when trade-offs and compromises must be addressed, and throughout the commissioning process to document the original design intent.<br>The CHPS Eligibility Criteria detailed in Volume III provides a flexible way to set goals. This point system covers the essential elements of high performance design and can be used by districts to clearly identify their priorities. |
| 2. **Site analysis and approval** | District selects site. SFPD conducts an initial review and may grant initial approval. The Department of Toxic Substances Control (DTSC) tests the site, and determines whether it is hazardous. After the site is deemed safe by the SFPD and DTSC, the site is approved. This process can take from a few months to several years to complete, depending on the level of toxins in the site and whether the surrounding community supports the construction. | **Minimize the impact of site.** Always consider location of site and maximize the transit options of students, teachers, and staff. Building on previously developed land preserves green space. If building on a new site, disturb as little of the natural environment as possible, and restore damaged portions of the site. Design to reduce stormwater runoff. |
| 3. **Selecting the A/E team** | The architectural and engineering (A/E) team must be competitively selected using qualification-based criteria. A fee is negotiated only after an A/E team has been selected on the basis of their qualifications. This process must be followed in order to receive state funding. | **Select design team with necessary qualifications** for designing a high performance school, and include the requirement for a high performance school in the negotiated design services.<br>**Communicate Goals to Designers.** Goals included in the educational specifications and designer Request for Proposals clearly communicate your design intentions. |
| 4. **Schematic Design** | During the conceptual design phase, key decisions on the basic scale and layout of the facility are made, and the project's overall scope and direction are established. | **Verify that High Performance Goals have been addressed.** Many key elements of the design are decided at this phase; modifying these decisions at later stages may prove to be difficult, costly, and sometime impossible.<br>**Pursue Integrated Design.** Insist on the development of an integrated design team to take full benefit of design options that affect the entire building performance. |
| 5. **Design Development** | The design is refined and finalized as key building systems and materials (architectural, structural, mechanical, and electrical) are chosen and integrated. Depending on plan approvals, iterations between the designers and CDE/DSA may occur. | **Use goals as guides.** Trade-offs and compromises are inevitable as the design develops. Be sure that the impacts of design tradeoffs to the total building performance have been investigated by the designers. |

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| | | | |
|---|---|---|---|
| 6. | **Construction Documents** | All design elements are finalized and the documents (drawings and specifications) that will guide the construction of the building are completed. | **Clearly specify high performance materials and equipment.** Many contractors do not have experience with high performance design or "green" materials, especially interior products such as carpets, low-VOC paints, adhesives, and surface finishes. Clearly specifying them in the contract documents will help ensure that the correct materials are used.<br>Clearly identify a substitution and review process that includes the design team and the district, and includes the necessary time to reject a substitution request. The intent of the specifications are sometimes violated in this substitution process. |
| 7. | **Plan Approval** | **Initial CDE Plan Approval.** The SFPD evaluates a schematic and final design of the proposed school in the context of the educational specification and school site safety. Once they feel that the design supports the district's educational mission and have determined that the site is free of hazards, they grant initial approval.<br>**Final Plan Approval.** The final architectural and engineering plans are submitted to the DSA and SFPD for independent review. Plans do not need to be submitted concurrently. The districts must make all changes recommended by the DSA and SFPD prior to approval. | |
| 8. | **Funding** | **Secure Local Funding.** Funding efforts that began with the decision to construct or renovate the building are secured. Districts seeking state money must secure 50% of the cost for new construction and 20% for renovations.<br>**SAB Eligibility Approval.** If receiving state money, districts apply to the OPSC and must verify their eligibility in the program by proving a need for the construction. This can be done at any time in the design process, but must precede SAB approval.<br>**SAB Funding Approval.** If receiving state money, districts apply to OPSC for funding and must provide proof that (1) local funding has been secured, (2) plans have been approved by DSA and SFPD, and (3) the site and plans have been approved by the CDE. In the event the district is unable to share in the construction cost, the district can pursue financial assistance through hardship provisions. Once the completed application is received, OPSC processes the application and forwards it to SAB for final approval and release of state funds. | **Communicate the value of High Performance Design to community to help secure funding.** Educating the community about the academic, health, environmental, and monetary benefits of high performance design can help raise awareness and support for the new school. |
| 9. | **Bidding** | Construction projects are competitively bid. The majority of contractors do not have experience with high performance design elements, and care must be taken to ensure that the design is not compromised during construction. | **Communicate goals to the contractors.** The bid process should require that competing contractors have experience and qualifications to construct high performance schools, including commissioning. If this is not appropriate, care should be taken that substitutions are made with caution and only replaced with materials with equal or better performance. |
| 10. | **Construction Administration** | After the district hires the contractor, SAB releases the funds and construction begins. With all approvals and funding in place, the actual construction time on an average high school of 2,000 students takes approximately two years. Middle and elementary schools take less time. Total design development and construction time from concept to occupancy is between 2 to 4 years. When construction is complete, OPSC will perform a final audit. | **Monitor Construction.** Be wary of substitutions or design changes (change orders) during construction that might occur without consulting the designer. |
| 11. | **Occupancy** | Post occupancy review and evaluation. | **Verify Goals.** Commission the building to prove that you are getting what you paid for, and that the building has been built as designed, and designed to your specifications.<br>**Train occupants.** Maintenance personnel, teachers, and staff must understand how to use the building to maximize their comfort and building performance. |

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# DISCUSSION GUIDE

This Discussion Guide presents a step-by-step method for managing the design process in order to ensure that a high performance school building is achieved.

The Guide contains a series of questions, organized by design phase, that the "owners" of a new school (the superintendents, business officials, board members and others who are guiding the facility development process) can use to make sure their design team actively considers *all* the key components of a high performance school during *every* phase of the development process.

## Using the Discussion Guide

Over the course of designing and building a new facility, school representatives will meet regularly with their design team to discuss progress. Use the Process Guide to help guide discussion during these meetings.

The Guide is divided into eight sections corresponding to key phases in the design/development process:

- Programming and Goal Setting
- Selecting the A/E Team
- Site Analysis
- Schematic Design
- Design Development
- Construction Documents
- Bidding
- Construction Administration

At the start of each phase, consult the appropriate section of the Discussion Guide. Throughout this phase of the process, use the list of questions to help frame discussions with the design team. The questions in each section of the Guide address the key "building blocks" of any high performance school:

- Acoustic comfort
- Commissioning
- Daylighting
- Energy analysis tools
- Environmentally preferable materials and products
- Environmentally responsive site planning
- High performance heating/ventilating/air-conditioning systems
- High performance electric lighting
- Life-cycle cost analysis
- Renewable energy
- Safety and security
- Superior indoor air quality
- Thermal comfort
- Visual comfort
- Water efficiency

## Programming and Goal Setting

Note: The CHPS Eligibility Criteria (Volume III of the Manual) is an flexible and convenient means to define your high performance goals.

### Superior Indoor Air Quality

☐ Has superior indoor air quality been established as a design goal for the project?

### Acoustic Comfort

☐ Has good classroom acoustics been established as a design goal for the project?

### Thermal Comfort

☐ Has thermal comfort been established as a design goal, especially for the classrooms?

### Visual Comfort

☐ Has visual comfort been established as a design goal, especially for the classrooms?

### Daylighting

☐ Has providing optimum amounts of daylight been specifically established as a design goal for the school and, in particular, for the classrooms?

### Safety and Security

☐ Has security been established as a design goal for the project?
☐ As part of programming, are basic room placements and adjacencies being considered in terms of their effects on safety and security (for example, is the main entrance visible from the administrative offices, etc.)?

### Life-Cycle Cost Analysis

☐ Has using some form of life-cycle cost analysis methodology been established as a requirement for the design team?
☐ What methodology will be used?
☐ What basic assumptions (for example, projected life of the facility; projected energy costs; rate of inflation, etc.) have been built into the methodology? Are they agreed to by all parties?

### Commissioning

☐ Has commissioning been committed to, and budgeted for, as a basic component of the project?
☐ Has a commissioning agent been engaged?

### Energy Analysis Tools

☐ Is the design team required to use an energy analysis tool to help maximize the energy effectiveness of the building?
☐ What tool has been selected?
☐ At what stages in the design process will the tool be used and what types of analyses will be developed?
☐ Has an energy use goal (that is, a maximum amount of nonrenewable energy the school should consume in a year) been established? What is it?

### Energy Efficient Building Shell

☐ Has providing an energy efficient building shell been established as a goal for the project?

- ☐ Does the basic programming allow windows on the east and west to be smaller (to reduce unwanted heat gain) and those on the north and south to be larger (to enhance daylighting opportunities)? For example, does the programming group functions that may need less glazing (auditoriums, kitchens, etc.) on the east and west, and those that will benefit from daylight (classrooms, corridors, etc.) on the north and south?

### Environmentally Preferable Materials and Products

- ☐ Has using environmentally preferable materials and products (to the extent feasible) been established as a design goal?
- ☐ Is there agreement between the owner and design team as to the types of environmentally preferable materials and products that should be considered for the project? Are these prioritized?

### Waste Reduction

- ☐ Has design for materials efficiency been established as a goal?
- ☐ Has construction waste management been established as a goal? Have specific goals for waste reduction been set?

### Environmentally Responsive Site Planning

- ☐ Is preserving natural areas on the site established as a design goal?
- ☐ Is minimizing stormwater runoff a design goal for the site?
- ☐ Have goals for alternative transporation been established?
- ☐ Does the community support the environmental and visual impacts of the school on the site and surrounding area? Have minimizing these impacts been established as a design goal?

### High Performance HVAC

- ☐ Is using high efficiency heating, ventilating and air-conditioning equipment a design goal for the project?
- ☐ Is "right sizing" this equipment (by accurately predicting demand and sizing the equipment to meet it) a design goal?

### High Performance Electric Lighting

- ☐ Is a high performance electric lighting system—especially in the classrooms—a design goal?
- ☐ Is optimizing the interaction between the electric lighting system and any daylighting strategies a design goal?

### Water Efficiency

- ☐ Has water efficiency been established as a design goal for the project?
- ☐ Have water use goals for the school been established?

### Renewable Energy

- ☐ Is maximizing the cost-effective use of renewable energy a design goal for the project?
- ☐ What percentage of the projected annual energy use of the facility should be provided by renewable energy systems? Is this percentage agreed to by all parties?
- ☐ Will the district need to hire a qualified technition to maintain the renewable energy souces? What school district budgets and trade union issues will need to be addressed?

## Selecting the A/E Team

**Superior Indoor Air Quality**

- What is the team's approach to delivering superior indoor air quality?
- In previous projects how has the team addressed: controlling sources of contaminants in a building; providing adequate ventilation; and avoiding moisture accumulation?
- Have any of their buildings experienced indoor air quality problems that required remedial action?

**Acoustic Comfort**

- How has the team addressed acoustic performance in previous projects?
- What specific strategies has the team used to ensure acoustic quality?
- How has the team applied these strategies in classrooms, muti purpose rooms, stages, music , and hallways?

**Thermal Comfort**

- What is the team's approach to maintaining thermal comfort in the buildings they design?
- How much control will teachers have over their individual classrooms? Why is this method proposed?

**Visual Comfort**

- What is the team's approach to ensuring visual comfort in the buildings they design?
- Do they have examples (preferably classrooms) that can be visited and "test driven"?

**Daylighting**

- What examples can the team provide of previous projects that incorporate daylighting?
- What daylighting strategies did the team use?
- Are the occupants satisfied with the results?
- Are the strategies saving energy? How much?
- What analysis tools does the team use to optimize performance of the daylighting systems it designs?

**Safety and Security**

- Does the team have experience with Crime Prevention through Environmental Design (CPTED)?
- How has the team incorporated CPTED principles into previous projects (preferably schools)?
- How does the team balance the use of security technology and the use of CPTED principles in its buildings? Does it emphasize "security by design" first and technology second?

**Life-Cycle Cost Analysis**

- Has a life-cycle cost analysis been included in the contract?
- What life-cycle cost methodology does the team use on its projects?
- How does it use the methodology to reduce the total ownership costs of the buildings it designs?
- Has it applied the methodology to school design? What were the results?
- What methodology does the team propose for the project under discussion?

**Commissioning**

- Have any of the team's previous buildings gone through a commissioning process?
- How detailed was the commissioning? Who acted as commissioning agent?

- What were the results?

### Energy Analysis Tools

- What energy analysis tools does the team use on its projects?
- How does it use these tools to reduce energy consumption in its designs?
- Has it applied the tools to school design? What were the results?
- What tools does the team propose for the project under discussion?

### Energy Efficient Building Shell

- How has the team provided energy efficient walls, floors and roofs on previous projects?
- What key techniques, materials and products were used and what was the resulting impact on energy performance?
- Are the systems still performing as designed?

### Environmentally Preferable Materials and Products

- What experience does the team have in specifying environmentally responsible materials and products in its projects?
- Does the team have knowledge of how these materials and products can be procured, what delivery timelines can be expected, and how they are installed?
- Does the team have knowledge of how these materials and products perform over time?
- Has the team ever specified environmentally responsible materials and products for schools?

### Waste Reduction

- Does the team have experience designing for materials efficiency?
- Has the team experience specifying construction waste management?

### Environmentally Responsive Site Planning

- Does the team have experience creating environmentally responsive site plans?
- What were the key features and how are they performing?

### High Performance HVAC

- Does the team specify high performance HVAC systems as standard practice?
- What tools does the team use to analyze and optimize the performance of HVAC systems?
- What high performance HVAC systems has the team put in place in previous projects (preferably schools)?
- How much energy savings did these systems generate?
- How have these systems performed over time?
- Did these system provide a quiet, as well as comfortable, learning environment?

### High Performance Electric Lighting

- Does the team have experience designing high performance electric lighting systems (preferably in schools)?
- Are these systems providing a high quality visual environment and saving energy?
- What is the team's experience integrating daylighting and electric lighting systems?
- What tools does the team use to analyze and optimize the combined performance of daylighting and electric lighting systems?

### Water Efficiency

- What is the team's experience with water efficient landscaping, water use reduction techniques, and/or innovative wastewater treatment systems?

- Have they applied any of these techniques to schools?
- What have been the results?
- Does the community support the use of reclaimed/gray water systems? What educational efforts would be needed to build their support?

**Renewable Energy**

- What is the team's experience designing and/or installing renewable energy systems?
- What specific systems have they used or installed (preferably in schools)?
- How much energy are these systems saving?
- Are they still performing as intended?

# Site Analysis

**Superior Indoor Air Quality**

- Is the site near any current or planned sources of outdoor pollution?
- What are the ambient outdoor air quality conditions and prevailing wind direction(s)?

**Acoustic Comfort**

- Are there major sources of noise near the site (for example, highways, shopping areas)?
- Can the site be used to minimize the impacts of these noise sources (for example, through plantings, earth berms, etc.)?

**Thermal Comfort**

- Are there prevailing breezes that could be used to help naturally ventilate the building?

**Visual Comfort**

- Does the site provide special views that should be preserved?

**Daylighting**

- Does the site allow the building to be oriented on an east-west axis, maximizing southern exposure?
- How will site elements (for example, existing trees or adjacent buildings) affect the building's access to sunlight?

**Safety and Security**

- Are there clear lines of sight to and from the school building from throughout the site?
- Are there areas (for example, depressions in the ground, stands of trees, thick shrubs) where people can be hidden from view?

**Life-Cycle Cost Analysis**

- N/A

**Commissioning**

- N/A

**Energy Analysis Tools**

- N/A

**Energy Efficient Building Shell**

- N/A

**Environmentally Preferable Materials and Products**

- Are there materials on the site that can be used in the building project?
- Does the site naturally lend itself to the use of certain environmentally preferable materials?

**Waste Reduction**

- Can any of the materials on the site, especially if it is previously developed, be safely salvaged or reused in the new construction (landscaping materials, concrete, interior materials)?

**Environmentally Responsive Site Planning**

- Can existing natural areas or features on the site be preserved?
- Does the site lend itself to controlling stormwater runoff?

- Can areas of the site be restored?
- Can connections to nearby ecosystems be maintained?
- What areas of the site could be used as "outdoor laboratories" for teaching?
- If the site has been previously developed, what are the opportunities for reuse of buldinng/site materials?
- What toxin risks are preset on or near the site?
- How many alternative transporation options are easily accessible from the site?
- Will pedestrians and individuals using bikes have save access to the school?

**High Performance HVAC**

- N/A

**High Performance Electric Lighting**

- N/A

**Water Efficiency**

- Does the site lend itself to the use of high efficiency irrigation techniques?
- Can municipal supplied reclaimed water be used for irrigation? Does the community, parents, and school board support such a plan?
- Could the site accommodate on-site wastewater treatment? Who would be responsible for its maintenance and operation?

**Renewable Energy**

- Does the site have good solar access—for daylighting, active and passive solar heating, solar hot water, and/or photovoltaic systems?
- Could the site use wind power to generate electricity?

# Schematic Design

**Superior Indoor Air Quality**

- ☐ Will the HVAC system being considered provide adequate ventilation, and how will the design team verify that these goals are being met?
- ☐ Does the basic layout of the school keep operable windows and air intake vents away from sources of exhaust (such as cars and buses)?
- ☐ Do the preliminary selected materials support superior indoor air quality by limiting VOCs and other off-gased pollutants?
- ☐ Will extreme roof or surface temperatures adversely affect the performace of the HVAC system (including air intakes and duct design)?

**Acoustic Comfort**

- ☐ Does the basic layout of the classrooms help or hinder good acoustics (in other words, does it dampen or magnify sound reverberation)?
- ☐ Do any of the classrooms face sources of outside noise, such as playgrounds, roads or equipment? If so, what measures are proposed to reduce the impact of this noise?
- ☐ Are any of the classrooms located next to sources of inside noise (music rooms, rooms that use amplified sound systems, etc.). If so, what measures are proposed to reduce the impact of this noise?

**Thermal Comfort**

- ☐ Are windows and skylights being designed to minimize "hot spots" caused by direct sunlight?
- ☐ Are temperature controls being considered for each classroom?

**Visual Comfort**

- ☐ Are the basic daylighting and electric lighting designs being developed so that they provide illumination as uniformly as possible, using task or accent lighting as appropriate to meet specific needs?
- ☐ Are individual lighting designs being developed for individual room types? Do the designs vary, even within room type, depending on the amount of daylight the room will receive?
- ☐ Is the potential for glare being analyzed, and are the lighting/daylighting systems being designed to minimize it?
- ☐ Are the color and texture of wall, floor and ceiling surfaces being taken into account in terms of their interaction with the lighting and their combined impact on the visual environment?

**Day lighting**

- ☐ What basic strategies are being considered for bringing daylight into the school, particularly the classrooms?
- ☐ What strategies are being considered to control unwanted heat gain and glare?
- ☐ What tools are being used to analyze the impact of any daylighting strategies on the electric lighting system and on visual comfort and energy use?
- ☐ What are the preliminary results of these analyses?

**Safety and Security**

- ☐ How have Crime Prevention through Environmental Design (CPTED) principles been applied during this phase of the process?
- ☐ Are opportunities for natural surveillance and access control being "designed in"?

- What security technologies are being considered? How do they reinforce and extend the impact of the school's security-focused design features?

**Life-Cycle Cost Analysis**

- Has the life-cycle cost methodology selected for the project been used to compare and optimize alternative design strategies at least once (preferably several times) during this phase of the process?

**Commissioning**

- Is appropriate design documentation being collected by and/or delivered to the commissioning agent?
- Has a preliminary commissioning plan been developed?

**Energy Analysis Tools**

- Has the energy analysis tool(s) selected for the project been used to project energy consumption at least once (preferably several times) during this phase of design?
- Do the results meet or exceed the energy goal for the facility?

**Energy Efficient Building Shell**

- What basic assemblies and configurations are being considered for the walls, floors and roofs of the facility?
- What types of materials—glazing, shading, insulation, air barriers, structural materials, etc.—are being considered?
- How are trade-offs being analyzed (for example, between amounts of window versus wall, between one type of glazing versus another, etc.), and how will the overall performance of the shell as a whole be optimized?
- How are the impacts of thermal mass being factored in?
- Are light-colored surfaces, particularly roofing, being considered as a means to reduce heat gain?
- Are the proposed roof colors in compliance with local building requirements and do they have the support of the community?

**Environmentally Preferable Materials and Products**

- What types of environmentally preferable materials and products are being considered and where will they be used?

**Waste Reduction**

- Does the basic design facilitate recycling by students and faculty?
- Will storage areas be desiginated in the design for the collection of these recyclables?

**Environmentally Responsive Site Planning**

- Is the building, particularly the classroom wings, oriented in a predominantly east-west direction to facilitate access to daylight?
- Does the design preserve existing natural areas or features on the site?
- Does the design help control stormwater runoff?
- Does design restore areas of the site?
- Are connections to nearby ecosystems being maintained?
- Does the design minimize areas covered with impervious surfaces (such as parking lots, paved walkways, etc.)?
- Are their any opportunites to replacing any non-permeable surfaces with permeable surfaces?

**High Performance HVAC**

- What type of HVAC system is being considered for the school?
- Why is this system optimal from a comfort/energy performance standpoint?
- How are the interactions between the HVAC system and other key building systems (such as lighting, daylighting, building shell) being analyzed and optimized?
- Is natural ventilation being considered? If so, are its potential impacts on HVAC performance being factored into the analysis process?
- Can the HVAC equipment be shaded with building or landscaping elements to reduce solar gain?
- Will the acoustics or air flow of the system adversely affect the learning environment? Have drafts been eliminated?

**High Performance Electric Lighting**

- What electric lighting system is being proposed for the school and, in particular, for the classrooms?
- What are its energy and visual performance benefits?
- How does it interact with the daylighting strategies being used?
- How are these interactions being analyzed and optimized?
- Will the control systems perform as expected during both active and quiet classroom activities?

**Water Efficiency**

- Is water efficient landscaping part of the preliminary site design?
- Is irrigating only the athletic fields, not plants near buildings or parking lots, being considered?
- Are water reduction techniques being considered for school plumbing fixtures and equipment?
- Is capturing and reusing rainwater being considered?
- Are innovative wastewater treatment techniques being considered? Will any additional staff be needed to maintain or operate the systems?

**Renewable Energy**

- What renewable energy strategies are being considered for the school? Will any additional staff be needed to maintain or operate the systems?
- Are the systems as secure as possible to minimize the risk of valdalism?
- How much energy will they save?
- What are their life-cycle cost benefits?
- How will they impact the site plan or the building design?
- How will they impact other building systems (such as lighting, electrical, HVAC, building shell)?

# Design Development

**Superior Indoor Air Quality**

- ☐ Will the HVAC system provide adequate ventilation, especially to the classrooms?
- ☐ Is the system designed to maintain the indoor relative humidity between 30–50%?
- ☐ Does the design provide local exhausts for restrooms, kitchens, science labs, janitor's closets, copy rooms and vocational/industrial shop rooms? How are they controlled?
- ☐ Does the design include $CO_2$ sensors in large assembly areas to monitor air quality?
- ☐ Have cleaning products been identified that support good indoor air quality?
- ☐ What design elements have been included to facilitate integrated pest management to reduce the need for pesticides?

**Acoustic Comfort**

- ☐ How do the proposed materials and finishes, especially those used in the classrooms, contribute to reducing sound reverberation?
- ☐ Have the classrooms been analyzed in terms of projected acoustic performance?
- ☐ Will the proposed heating/ventilating/air-conditioning (HVAC) system for the classrooms create noise? If so, how will the impacts of this noise be dealt with?

**Thermal Comfort**

- ☐ Are HVAC distribution layouts designed to ensure all parts of a room receive adequate ventilationwhlie eliminating drafts?

**Visual Comfort**

- ☐ Do the daylighting and electric lighting system designs provide illumination as uniformly as possible, using task or accent lighting as appropriate to meet specific needs?
- ☐ What tools have been used to model the interactions of both these systems in terms of their impacts on visual comfort?
- ☐ Have direct/indirect lighting fixtures been selected for general illumination in classrooms?
- ☐ What shading strategies (internal and external) have been selected?
- ☐ Have individual lighting designs been developed for individual room types? Do the designs vary, even within room type, depending on the amount of daylight the room will receive?
- ☐ Has the potential for glare being analyzed, and have the lighting/daylighting systems been designed to minimize it?
- ☐ Have the color and texture of wall, floor and ceiling surfaces been taken into account in terms of their interaction with lighting and their combined impact on the visual environment?

**Daylighting**

- ☐ What daylighting strategies have been selected for the school, particularly the classrooms?
- ☐ Are the classrooms receiving as much daylight as possible, while avoiding glare and unwanted heat gain?
- ☐ What types of glazing have been selected (for windows, clerestories, skylights and/or roof monitors) and why are they more energy- and cost-effective than alternatives?
- ☐ How will the daylighting and electric lighting systems interact?
- ☐ What analyses have been done to optimize these interactions?
- ☐ Will the combined daylighting/electric lighting strategies reduce energy use and lower the school's operating costs over time?

- ☐ Has the possibility of reducing the number of light fixtures, or the number of lamps, in daylit rooms been investigated?

**Safety and Security**

- ☐ How have Crime Prevention through Environmental Design (CPTED) principles been applied during this phase of the process?
- ☐ Have opportunities for natural surveillance and access control been "designed in"?
- ☐ What security technologies have been selected? How do they reinforce and extend the impact of the school's security-focused design features?

**Life-Cycle Cost Analysis**

- ☐ Has the life-cycle cost methodology selected for the project been used to compare and optimize alternative design strategies at least once (preferably several times) during this phase of the process?

**Commissioning**

- ☐ Is appropriate design documentation being collected by or delivered to the commissioning agent?
- ☐ Has a commissioning report been prepared?

**Energy Analysis Tools**

- ☐ Has the energy analysis tool(s) selected for the project been used to project energy consumption at least once (preferably several times) during this phase of design?
- ☐ Do the results meet or exceed the energy goal for the facility?

**Energy Efficient Building Shell**

- ☐ What basic wall, floor and roof assemblies have been selected?
- ☐ What types of materials—glazing, shading, insulation, air barriers, structural materials—have been selected and why are they better, from an energy and life-cycle cost perspective, than other alternatives?
- ☐ How have trade-offs been analyzed (between amounts of window versus wall, between one type of glazing versus another, etc.), and how has the performance of the building shell as a whole been optimized?
- ☐ Have the impacts of thermal mass been factored in?
- ☐ Are light-colored surfaces, particularly roofing, being used as a means to reduce heat gain?

**Environmentally Preferable Materials and Products**

- ☐ What types of environmentally preferable materials and products have been selected and where will they be used?
- ☐ Are all the selected materials and products low emitters of indoor air contaminants?

**Waste Reduction**

- ☐ Does the final design facilitate recycling by students and faculty? How will the materials be stored?

**Environmentally Responsive Site Planning**

- ☐ Does the final design preserve existing natural areas or features on the site?
- ☐ Does final design restore areas of the site? How?
- ☐ Are connections to nearby ecosystems being maintained? How?
- ☐ Does the design help control stormwater runoff?
- ☐ Does the design minimize areas covered with impervious surfaces (such as parking lots, paved walkways, etc.)?

- Do landscaping strategies, particularly tree planting, enhance the building's high performance features (for example, by providing shade where it's needed but not blocking sunlight that's used for daylighting)?

### High Performance HVAC

- What type of HVAC system has been selected for the school?
- Why is this system optimal from a comfort/energy performance standpoint?
- Is it the best system from a life-cycle cost perspective?
- How have the interactions between the HVAC system and other key building systems (lighting, daylighting, building shell) been analyzed and optimized?
- Has natural ventilation been considered? If so, have its potential impacts on HVAC performance been factored into the analysis process?
- Has the HVAC equipment been "right sized" to meet predicted demand?
- What control system(s) has been selected and how will it affect performance?
- What level of control will individual teachers have over the heating, ventilating and air-conditioning of their classrooms?
- Is the entire system configured for easy operation, maintenance and repair?

### High Performance Electric Lighting

- What electric lighting system(s) has been selected for the school and, in particular, for the classrooms?
- What are its energy and visual performance benefits?
- How does it interact with the daylighting strategies being used? How have these interactions been analyzed and optimized?
- Have fewer fixtures and/or lamps been specified for daylit spaces?
- What control system(s) has been selected and how will it affect performance?
- What level of control will teachers have over the lighting in their classrooms?
- What is the energy performance and light distribution of the parking lot, outdoor, and field lighting? How much light pollution will be produced? Are they separately metered?
- To a reasonable extent, have the lighting fixtures been standardized to reduce the numbers of replacement parts that need to be stocked? What is the expected availabilty of replacement parts over the life of the building? How specialized is the equipment that has been recommended?

### Water Efficiency

- Has high efficiency irrigation technology been selected for athletic fields?
- Does the design use captured rainwater or recycled water for irrigation?
- Does the design include high efficiency equipment (dishwashers, laundry, cooling towers)?
- Does the design include low-flow showerheads and automatic lavatory faucet shut off controls?
- Does the design include innovative wastewater treatment techniques?

### Renewable Energy

- What renewable energy strategies have been selected and incorporated into the design?
- How much energy will they save?
- What are their life-cycle cost benefits?
- How do they impact other building systems (lighting, electrical, HVAC, building shell)?
- What analysis has been done to ensure that all these systems interact optimally?

## Construction Documents

**Superior Indoor Air Quality**

- ☐ Has a construction IAQ plan been required? Is a flush out required? Has time been allocated in the construction tme line for the proper flush out, and what measures have been taken to ensure that the contractors perform the flush out?
- ☐ Will the HVAC system as finally configured provide adequate ventilation, especially to the classrooms?
- ☐ Will the system maintain the indoor relative humidity between 30–50%?
- ☐ Are local exhausts with effective controls for restrooms, kitchens, science labs, janitor's closets, copy rooms and vocational/industrial shop rooms provided?
- ☐ Have $CO_2$ sensors in large assembly areas to monitor air quality been included?
- ☐ Are all the selected interior materials and products low emitters of indoor air contaminants?
- ☐ Have recessed grates or "walk off" mats been installed at entrances to reduce the amount of dirt entering the building? What are the maintenace impacts?

**Acoustic Comfort**

- ☐ Are the walls of classrooms that are located next to noise sources designed so that they reduce sound transmission?
- ☐ If rooftop HVAC equipment is being used, is it mounted on isolators to reduce sound transmission?

**Thermal Comfort**

- ☐ Do HVAC distribution layouts in their final configurations ensure all parts of a room receive adequate ventilation?
- ☐ Have controls been installed to provide teachers adequate control over the thermal comfort of their classrooms?

**Visual Comfort**

- ☐ Do the daylighting and electric lighting systems in their final configurations provide illumination as uniformly as possible, using task or accent lighting as appropriate to meet specific needs?
- ☐ Have direct/indirect lighting fixtures been specified for general illumination in classrooms?
- ☐ What shading strategies (internal and external) have been specified?
- ☐ Have the final configurations of other building components—like the color of the walls, floor or ceiling—been changed in ways that might influence system performance? Have the potential impacts of these changes on visual comfort been accounted for?

**Daylighting**

- ☐ Will the construction details for the daylighting components (the windows, light shelves, roof monitors, skylights, shading devices, etc.) modify the performance of the system as a whole; that is, will the required amount of daylight still reach the classrooms, will glare and heat gain still be controlled, etc.? What will be the impact—on operating costs and on visual comfort—of any changes in performance?
- ☐ Will the final construction details of other building components (for example, the color and reflectance of roofing materials adjacent to skylights or roof monitors) change the dynamics of the daylighting system and impact performance? What will be the impact—on operating costs and on visual comfort—of any changes in performance?
- ☐ What measures have been taken to eliminate leaks from the daylighting systems?

**Safety and Security**

- What type of exterior lighting has been specified and how will it improve security?
- Have durable materials been specified in critical areas such as entrances?
- What security technologies have been specified? How do they reinforce and enhance the building's security-focused design features?
- Have lens guards been specified in high activity areas like playgrounds, gyms, and fields?

**Life-Cycle Cost Analysis**

- Has the life-cycle cost methodology selected for the project been used to compare and optimize alternative design strategies at least once during this phase of the process?

**Commissioning**

- Have commissioning requirements been included in the construction documents?
- Has a written end-of-phase commissioning report been prepared?

**Energy Analysis Tools**

- Has the energy analysis tool(s) selected for the project been used to project energy consumption at least once during this phase of design?
- Do the results meet or exceed the energy goal for the facility?

**Energy Efficient Building Shell**

- Do the final construction details for the wall, floor and roof assemblies maintain the original design intent in terms of energy performance. (For example, do the assemblies allow insulation to be installed at the thickness originally specified, do air barriers cover all the areas they are supposed to, can areas such as roof cavities that need ventilation be adequately vented in the current configuration, etc.?)

**Environmentally Preferable Materials and Products**

- Are the construction documents clear and explicit concerning the required environmental performance of the materials and products specified?
- Is language included in the documents requiring that a proposed material or product substitution must be equal to or better than the specified product in terms of its environmental attributes?

**Waste Reduction**

- Has a construction waste management plan been required? Are goals specified for waste reduction and for job-site recycling within the contract documents and specifications?

**Environmentally Responsive Site Planning**

- Have hardy, indigenous plants been specified in the landscaping plan?
- Have exterior lights been designed to focus downward to reduce light pollution of the night sky?
- Has the exterior lighting been disigned with the nieghborhood and community in mind?

**High Performance HVAC**

- Do the equipment and products specified for the HVAC system continue to meet the design and performance goals established previously?
- What analyses have been done to ensure the system is "right sized" for the expected demand?Will it handle both current and projected demand?

**High Performance Electric Lighting**

- What lamps, ballasts and fixtures have been specified?

- Why are they the best choices in terms of visual comfort, energy use and long term performance? What are the manufacturer's warranties? What warrantees can be expected for replacement products?
- Will the system as finally configured and specified be easy to operate, maintain and repair?
- What is the impact of the system as finally configured on electricity use?
- Does the system as finally configured minimize waste heat generation? Has this been taken into account in sizing the cooling system?
- What controls have been specified? How will they help save energy and operating costs?
- What level of control will individual teachers have over the heating, ventilating and air-conditioning of their classrooms?

**Water Efficiency**

- N/A

**Renewable Energy**

- Do the final construction details for the renewable energy systems allow the systems to perform as designed? (For example, are solar systems installed so that they face the right direction, at the correct angle, to receive the right amount of sunlight? Does the final location of another current or planned building component—like a rooftop air conditioners—prevent sunlight from reaching a solar collector?) Are the solar collectors as vandel proff as possible?
- How are the renewable energy systems in their final configurations anticipated to perform from a life-cycle standpoint?
- What warranty periods have been specified for the systems? Who will service the system once the warranty has expired?

# Bidding

### Superior Indoor Air Quality

- Have any substitutions been proposed, such as alternative materials or a different ventilation system, that could impact indoor air quality?
- Are all substitute materials and their proposed cleaning agents low emitters of indoor contaminants?
- Do substitute materials require different cleaning processes that may contaminate indoor air?
- Are substitutions being proposed for materials or assemblies designed to act as barriers to sources of indoor contaminants? Will the substitute materials/assemblies also act as effective barriers?

### Acoustic Comfort

- Have any substitutions been proposed, such as alternative wall/floor/ceiling materials or different types of HVAC equipment, that could impact acoustical quality, particularly in the classrooms?
- If these substitutions are accepted, how will they impact overall acoustic comfort?

### Thermal Comfort

- Have any substitutions been proposed, such as alternative glazing materials, different types of insulation, or different types of ventilation hardware, that could affect thermal comfort, especially in the classrooms?
- If these substitutions are accepted, how will they impact the thermal comfort of students and teachers, the energy performance of the building and its life-cycle cost?

### Visual Comfort

- Have any substitutions been proposed, such as alternative glazing materials, different types of lamps or light fixtures, or alternative colors for walls, floors or ceilings, hat could affect visual comfort, especially in the classrooms?
- If these substitutions are accepted, how will they impact the visual comfort of students and teachers, the energy performance of the building and its life-cycle cost?

### Daylighting

- Have any substitutions been proposed, such as alternative glazing materials or different types of shading, that could impact the intended performance of the daylighting system?
- If these substitutions are accepted, how will they impact system performance, visual comfort and life-cycle cost?

### Safety and Security

- Have any material substitutions been proposed that could reduce the durability—and increase the vulnerability—of critical areas in the building, such as like entrances?
- Have any security technology substitutions been proposed?
- How well will the alternative technologies fit in with and complement the school's design-focused security measures?
- How will the substitute technologies interface with other controls systems in the school (for example, those for the lighting and HVAC systems)?
- If substitutions are accepted, will they be as easy to operate, maintain and repair as the originally specified products and systems?

**Life-Cycle Cost Analysis**

- Is the life-cycle cost methodology selected for the project being used to analyze proposed material or product substitutions in terms of their impacts on overall performance and cost effectiveness?

**Commissioning**

- Has the commissioning plan been clearly described to potential bidders?

**Energy Analysis Tools**

- Is the energy analysis tool(s) selected for the project being used to evaluate the energy consumption consequences of proposed materials, products or system substitutions?
- Do the substitutions impact the school's ability to meet its energy goal for the facility?

**Energy Efficient Building Shell**

- Have any substitutions been proposed, such as alternative glazing materials, different types of insulation, or alternative roofing products, that could impact the intended performance of the building shell?
- If these substitutions are accepted, how will they impact the energy performance of the building and its life-cycle cost?

**Environmentally Preferable Materials and Products**

- Are all proposed substitutions equal to or better than the specified products in terms of environmental attributes?
- Are the substitutions also functionally equivalent to the specified products? (In other words, if they are accepted, they will not adversely affect the performance of the system or assembly in which they are used.)
- What analyses have been done to ensure substitutions will not degrade environmental quality or system performance?

**Waste Reduction**

- Has a construction waste management plan that satisfies the goals of the project been submitted?

**Environmentally Responsive Site Planning**

- Have any substitutions been proposed, such as different plants, alternative materials for parking lots or walkways, or alternative exterior light fixtures, that could reduce the environmental quality of the site plan?
- Will any of these substitutions impact the performance of the building (for example, fewer trees may mean less shade and more heat gain in daylit classrooms)?
- Have these impacts been analyzed? How will they affect the overall life-cycle cost of the facility?

**High Performance HVAC**

- Have any substitutions been proposed, such as alternative equipment, different types of controls, or alternative delivery hardware (for example, diffusers), that could modify system performance?
- After the substitutions, will the system still be "right sized" to meet the demand (not over- or undersized)?
- If these substitutions are accepted, how will they impact the energy performance of the building and its life-cycle cost?

**High Performance Electric Lighting**

- Have any substitutions been proposed, such as alternative lamps, ballasts or controls, that could impact the intended performance of the electric lighting system?
- Will these substitutions provide the same level of visual comfort as the design calls for?
- Will they add any additional waste heat to the space?

- Will they work correctly with the specified control system?
- If these substitutions are accepted, how will they impact visual comfort, energy performance and life-cycle cost?

### Water Efficiency

- Have any substitutions been proposed, such as alternative plumbing fixtures, different types of landscape vegetation, or an alternative irrigation system, that could reduce the school's water efficiency?
- If these substitutions are accepted, how will they impact water use and overall life-cycle costs at the facility?

### Renewable Energy

- Have any substitutions been proposed to specific systems or to the materials from which the systems are constructed that could impact intended performance?
- If these substitutions are accepted, how will they impact the energy performance and life-cycle cost of the whole facility?

# Construction Administration

### Superior Indoor Air Quality

- Is the impact of the construction process on indoor air quality—for workers and, in the case of renovations, for students and teachers—being managed?
- Is the building being constructed as designed to ensure high indoor air quality?
- Have any substitutions been proposed, such as alternative materials or a different ventilation system, that could impact indoor air quality?
- Are all substitute materials and their cleaning agents low emitters of indoor contaminants?
- Do substitute materials require different cleaning processes that may contaminate indoor air?
- Are substitutions being proposed for materials or assemblies designed to act as barriers to sources of indoor contaminants? Will the substitute materials/assemblies also act as effective barriers?
- Is there a plan to "flush out" the facility for at least 72 hours after construction and before occupancy?

### Acoustic Comfort

- Is the building being constructed as designed to achieve acoustic comfort?
- Have any substitutions been proposed, such as alternative wall/floor/ceiling materials, or different types of HVAC equipment, that could impact acoustical quality, particularly in the classrooms?
- If these substitutions are accepted, how will they impact overall acoustic comfort?

### Thermal Comfort

- Is the building being constructed as designed for optimal thermal comfort, especially in the classrooms?
- Have any substitutions been proposed, such as alternative glazing materials, different types of insulation, or different types of ventilation hardware, that could affect thermal comfort, especially in the classrooms?
- If these substitutions are accepted, how will they impact the thermal comfort of students and teachers, the energy performance of the building and its life-cycle cost?

### Visual Comfort

- Is the building being constructed as designed to enhance visual comfort, especially in the classrooms?
- Have any substitutions been proposed, such as alternative glazing materials, different types of lamps or light fixtures, or alternative colors for walls, floors or ceilings, that could affect visual comfort, especially in the classrooms?
- If these substitutions are accepted, how will they impact the visual comfort of students and teachers, the energy performance of the building and its life-cycle cost?

### Daylighting

- Is the building, especially the classrooms, being constructed as designed to provide the appropriate or intended levels of natural light?
- Have any substitutions been proposed, such as alternative glazing materials or different types of shading, that could impact the intended performance of the daylighting system?
- If these substitutions are accepted, how will they impact system performance, visual comfort and life-cycle cost?
- Have the controls been properly installed and commissioned?

### Safety and Security

- Is the building being constructed as designed to improve security?
- Are security technologies being installed as designed?
- Have any material substitutions been proposed that could reduce the durability—and increase the vulnerability—of critical areas in the building such as entrances?
- Have any security technology substitutions been proposed?
- How well will the alternative technologies fit in with and complement the school's design-focused security measures?
- How will the substitute technologies interface with other controls systems in the school (for example, those for the lighting and HVAC systems)?
- If substitutions are accepted, will they be as easy to operate, maintain and repair as the originally specified products and systems?

### Life-Cycle Cost Analysis

- Is the life-cycle cost methodology selected for the project being used to analyze proposed material or product substitutions in terms of their impacts on overall performance and cost effectiveness?

### Commissioning

- Has the commissioning plan been implemented?
- Has the functional performance of key systems been tested and verified?
- Are the results documented in a commissioning report?
- Have appropriate school staff been trained concerning proper operation of system equipment and controls?

### Energy Analysis Tools

- Is the energy analysis tool(s) selected for the project being used to evaluate the energy consumption consequences of proposed materials, products or system substitutions?
- Do the substitutions impact the school's ability to meet its energy goal for the facility?

### Energy Efficient Building Shell

- Is the building shell being constructed as designed to achieve a high level of energy efficiency?
- Have any substitutions been proposed, such as alternative glazing materials, different types of insulation, or alternative roofing products, that could impact the intended performance of the building shell?
- If these substitutions are accepted, how will they impact the energy performance of the building and its life-cycle cost?

### Environmentally Preferable Materials and Products

- Is the building being constructed using the environmentally preferable products specified?
- Are all proposed substitutions equal to or better than the specified products in terms of environmental attributes?
- Are the substitutions also functionally equivalent to the specified products? (In other words, if they are accepted they will not adversely affect the performance of the system or assembly in which they are used.)
- What analyses have been done to ensure substitutions will not degrade environmental quality or system performance?

### Waste Reduction

- Is the construction waste management plan being carried out?
- Are efforts being made to minimize construction waste?

- Is some percentage of demolition and/or land-clearing waste being salvaged or recycled?

**Environmentally Responsive Site Planning**

- Is the site being constructed and landscaped in the environmentally responsive way it was designed?
- Have any substitutions been proposed, such as different plants, alternative materials for parking lots or walkways, or alternative exterior light fixtures, that could reduce the environmental quality of the site plan?
- Will any of these substitutions impact the performance of the building (for example, fewer trees may mean less shade and more heat gain in daylit classrooms)?
- Have these impacts been analyzed? How will they affect the overall life-cycle cost of the facility?

**High Performance HVAC**

- Is the HVAC system being installed as designed to achieve high performance?
- Have any substitutions been proposed, such as alternative equipment, different types of controls, or alternative delivery hardware (for example, diffusers), that could modify system performance?
- After the substitutions, will the system still be "right sized" to meet the demand (not over- or undersized)?
- If these substitutions are accepted, how will they impact the energy performance of the building and its life-cycle cost?

**High Performance Electric Lighting**

- Is the electric lighting system being installed as designed to achieve high performance?
- Have any substitutions been proposed, such as alternative lamps, ballasts or controls, that could impact the intended performance of the electric lighting system?
- Will these substitutions provide the same level of visual comfort as the design calls for?
- Will they add any additional waste heat to the space?
- Will they work correctly with the specified control system?
- If these substitutions are accepted, how will they impact visual comfort, energy performance and life-cycle cost?

**Water Efficiency**

- Are the building and grounds being constructed as designed to conserve water?
- Have any substitutions been proposed, such as alternative plumbing fixtures, different types of landscape vegetation, or an alternative irrigation system, that could reduce the water efficiency of the school?
- If these substitutions are accepted, how will they impact water use and overall life-cycle costs at the facility?

**Renewable Energy**

- Are the renewable energy systems being installed as designed to achieve high performance?
- Have any substitutions been proposed—to specific systems or to the materials from which the systems are constructed—that could impact intended performance?

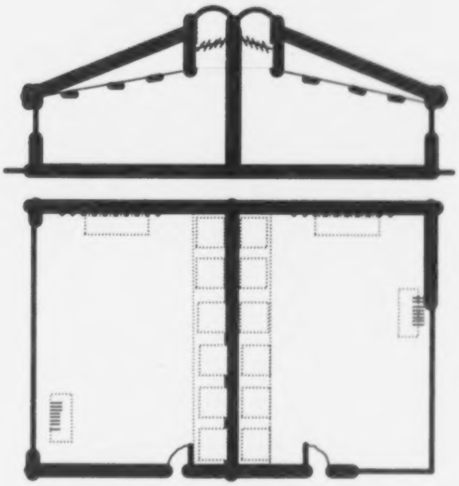
# CASE STUDY 1: DAYLIT CLASSROOM

**Oakridge High School**
**Location: El Dorado Hills, CA**
**Architect: Nacht and Lewis**

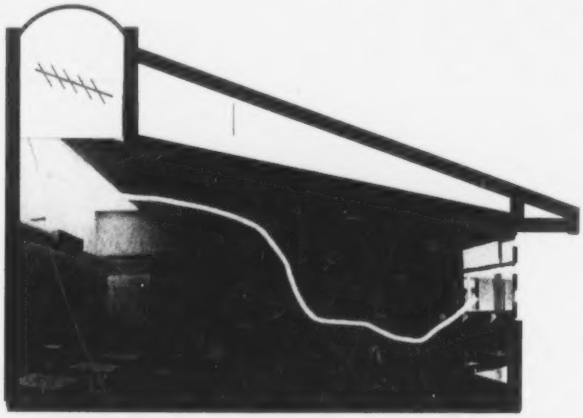
## Design Summary

The architectural program for Oakridge High School called for 40 classrooms and associated learning spaces, serving approximately 2000 students. The design team had worked together for many years, and were just completing a major daylighting and energy efficiency demonstration project in Sacramento. With this strong working background, the design team convinced the school district to pursue a dynamic daylighting, low-energy design approach.

The innovative school they designed provides an excellent example of balanced, low-glare daylight throughout the day. Their design uses a combination of 3 different daylighting guidelines to create bright, even illumination across each classroom. The architects combined Wall Wash Toplighting (Guideline DL4) along the interior shared classroom wall with both View Windows (Guideline DL1) and High Clerestory Windows (Guideline DL2) on the exterior wall. A linear surface-mounted fluorescent electric lighting scheme is controlled in response to the daylight.



*Plan and Section of Oakridge High School classrooms. Graphic courtesy of Kalpana Kuttiah, HMG*



***Oakridge High School, Daylight Illumination Levels, north-facing classroom, 11 A.M., clear September day. Lisa Heschong, Photographer***

### Daylighting

Classroom wings consist of back-to-back classrooms with window walls facing either north or south, and exterior circulation. A scissor-trussed roof allows the ceiling to slope from a high of about 13 ft at the edge of the skylight well to a low of 10 ft at the exterior wall. Wall wash toplighting is accomplished by two rows of skylights lining either side of the shared interior wall between classrooms. The key to the design is the diffusing skylights (a linear series of 4 ft x 4 ft, double glazed prismatic domes) that have high visible light transmittance, while scattering all direct sunlight into a gentle, diffuse light.

> *"It's possible to run the school even if power goes off. It doesn't happen often, but we recently had one morning without power for 2-3 hours and didn't need to cancel classes!" —Oakridge High School Facility Manager*

The skylights sit atop a white rectangular well that is about 4 ft deep. The prismatic lens and adjacent white walls spread diffuse, low glare, ambient daylight across two-thirds of the room. Manually operated louvers in the skylight well provide additional diffusion and allow teachers to modulate daylight levels, darkening the room for AV presentations if desired. A pair of venting skylights in each classroom can also be manually operated to complement the operable windows, allowing through ventilation for the classroom.

Light from the skylights is balanced by clear, double-glazed windows on the exterior wall that extend up to 9 ft—as high as possible in this outer wall. The upper portion provides daylight deeper into the space and the lower portion gives views to the exterior. The upper and lower window sections are separated only by a mullion.

Roof overhangs and covered walkways shade south windows from direct sun penetration in summer months and reduce brightness of the view on both north and south elevations. Extensive landscaping was designed to further reduced sun penetration and window brightness. But the original trees, unfortunately damaged by vandalism in 1990, no longer shade the south windows. Since the south windows are now exposed to some direct sun in the winter, some south-facing classrooms have been retrofitted with window film to reduce visible transmission to about 20%. This solution to the window brightness problem is less successful than the original landscaping.

The teaching wall is always located on the solid east or west wall so the window and skylight walls flank the main classroom viewing direction. Providing daylighting from both sides results in a comfortable working light for both teachers and students. The daylight apertures are outside the normal viewing angles and eliminate shadows with balanced light from opposite directions.

On a clear fall day, daylight levels on desktops vary from a high of 125 footcandles directly under the skylight to a low of 31 footcandles about 6 ft from the window wall. Vertical illuminance on the walls averages about 40 footcandles, and varies between 60 to 25 footcandles. These values are well within recommended classroom light levels and within a comfortable range of variation. The ceiling and upper portions of the walls are painted white to reflect daylight in the space. In north classrooms, the lower walls are a warm beige or rose color to balance the cool north daylight; the warmer

*Overhangs and vegetation were designed to shade windows and prevent reflected glare. Curtains or blinds in windows provide additional control. Lisa Heschong, Photographer* daylight in south classrooms is balanced with cooler blues and greens.

### Electric Lighting

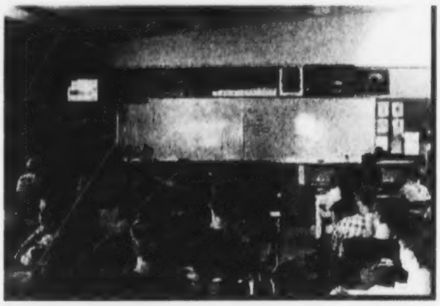
*First row of lights switched off. Note video screen located in darkest corner of room. Also note glare on whiteboard from windows placed in the back wall of a few classrooms. Lisa Heschong, photographer*

Electric light was originally provided by three rows of pendant-mounted indirect luminaires running parallel to the window wall. In 1995, these fixtures were replaced with three rows of surface-mounted, linear lensed ceiling luminaires as part of an energy efficiency retrofit. The T-8 lamps and electronic ballasts in the new luminaires reduced the lighting power density in the classroom down to 1.4 watts per square foot, well within energy code standards. Although the new luminaires provide a good, even illumination of 40–60 footcandles on every desk, they don't brighten the ceiling as much as the earlier pendants and create more potential for glare in VDT screens as the bright lenses are seen in contrast against the darker ceiling.

### Lighting Controls

Teachers have complete control of daylight levels in the space. A series of manually operated louvers in the skylight well allows teachers to regulate the amount of daylight entering the classroom from the skylights. Blackout drapes can be closed to adjust the daylight from the window wall. The upper and lower glazings do not have separate blinds, so they must be adjusted at the same time.

Since the electric lights run parallel to the window wall and skylight wall slot, they are aligned correctly to be switched in response to changing daylight levels. The first row of light fixtures nearest the skylight is automatically controlled to turn on and off in response to the daylight level. A rough estimate of energy savings from this switching scheme suggests potential energy savings of $75 to $150 per classroom per year. The original lighting design called for dimming controls, but currently both lamps in the fixtures are simply turned on or off in response to a signal from the photosensor. Some of the teachers find the switching distracting, and as a result many of the automatic controls have been disabled. Currently these controls are working in only about 20% of the classrooms. Unfortunately, once a control has been disabled, it tends to stays that way, even if a new teacher moves into the room. The teachers also have wall switches to control the lights. (The District has also installed occupancy sensors in some new classrooms which were built without the daylighting features.) Many teachers reportedly feel comfortable operating their daylit classrooms without the electric lights on for a good part of



*Lights off, but skylight louvers and curtains open, during video lesson. Lisa Heschong, photographer* the year. The actual energy savings due to local control of the lights has not been monitored for this school.

South exterior of Oakridge High School. Overhangs shade the south windows. New trees have been planted to replace vandalized vegetation. White roof and split face CMU walls have held up well. Lisa Heschong, photographer

### Other High Performance Features

The school design also included other key features to reduce operating costs. A white enameled standing seam metal roof was selected to reject heat build up. Built before the concept "cool roofs" was coined, this roof is a very appropriate choice for the hot Central Valley. Billed as a "life time roof," it has had absolutely no maintenance requirements in the 17 years since construction. The sloped, standing seam roof seems to have successfully discouraged students from climbing up on the roof. However, the District does have a few problems to resolve in the near future: some recently retrofitted vents have leaked, and paint on a few of metal panels is starting to peel.

The design team also selected a low maintenance, high-thermal mass material for the exterior walls. The split face concrete masonry units (CMU) have held up extremely well. They are uninviting to graffiti, and are easy to sandblast if any shows up. The filled CMU, insulated on the inside, was chosen to provide a thermal lag effect to the Valley's daily heat swings. Unfortunately, a recently installed, district-wide energy management system has not yet been optimized to account for this particular school's very different thermal load patterns.

## Construction Costs

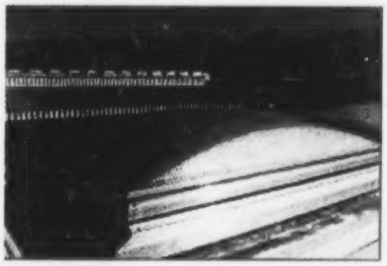
In spite of the aggressive daylighting design, the school had to meet the state's budget allocation at the time. The design team's objective was to design a school with extremely low operation costs for both energy and maintenance. Even though there was no extra money for the efficiency measures, the project managed to come in more than $150,000 below budget. The architect's basic strategy was to work with good orientation, a simple plan, and durable, low maintenance materials.

Operable louvers are not actively used. Lisa Heschong, photographer

## Lessons Learned

1. Teaching Wall: There is no separate illumination to highlight the teaching wall, so it appears darker than the skylit side wall. This is not a problem as long as students are facing the teaching wall. Some classrooms have windows along the back wall, in addition to the side wall. These can cause reflected glare off of the whiteboard, especially when the sun hits the white eaves of the roof.

2. **Computer Screens:** In some classrooms, computers are located opposite the teaching wall and have a view down the length of the classroom. Here, reflections in the monitor screens from windows or the linear, surface-mounted electric lights can make some areas of the screens almost illegible. In other classrooms, computer terminals are located along the window wall facing the windows. The window wall location creates glare by putting the bright window directly within the normal view of the screen. In these classrooms the curtains are usually drawn. This situation could be largely resolved by turning the computer screens 45 degrees away from the window wall.



*Prismatic skylights diffuse sunlight successfully. Installation has not leaked in 17 years since construction. Lisa Heschong, photographer*

3. **Skylight Maintenance:** There has been no leakage from any of the skylights, except when one of the operable units has been left open during a storm. No skylight repairs have been required during their 17 years of operation.
4. **Skylight Vandalism:** The skylights have proven to be less of a vandalism problem than the windows. There was no vandalism or skylight breakage for the first 14 years of operation. Then in 1998, a new building was added that allowed easy access to one of the classroom wing's roof. Thereafter, someone got up on the roof and intentionally broke two skylights. However, in the same time period, there have been about 8–10 intentional window breakages *per year*. Overall, the facility manager does not consider the skylights to be an "attractive nuisance" (in other words, a design feature that some people might find tempting to vandalize).
5. **Skylight Louvers:** The skylight louvers are not used very often by the teachers to darken the room. This may be because the manual device used to control the louvers is somewhat awkward to operate. It is possible to show a video in the classroom with the louvers open and lights off, so there's no real reason to close the louvers.
6. **Operable Vents:** Experience has shown that teachers rarely use the operable venting feature of the skylights. This manual device is also awkward to operate. Teachers may complain about stuffy rooms, but they rarely think to use the natural ventilation option.
7. **Reflected Daylight Glare:** The vertical eves of the white roof are very reflective of low angle sun and cause glare in classrooms opposite them. This could be ameliorated by painting the eaves a darker color. Originally, this low angle sun was largely blocked by mature landscaping.
8. **Electric Lighting Maintenance:** The maintenance supervisor has commented that it was much easier to replace lamps in the previous pendant lights (easily done from a six foot ladder). The current surface-mounted fixtures are much more difficult to reach and the lens occasionally slips off its hinges.
9. **Switching Controls:** Automatically switching of an entire row of lights has proven distracting. It has been disabled in a majority of the classrooms, which has reduced the energy savings accordingly. Possible solutions would be to use the original dimming scheme, to switch the lights in smaller increments (perhaps only one row of lamps at a time, instead of two) or to only allow switching during passing periods between classes.

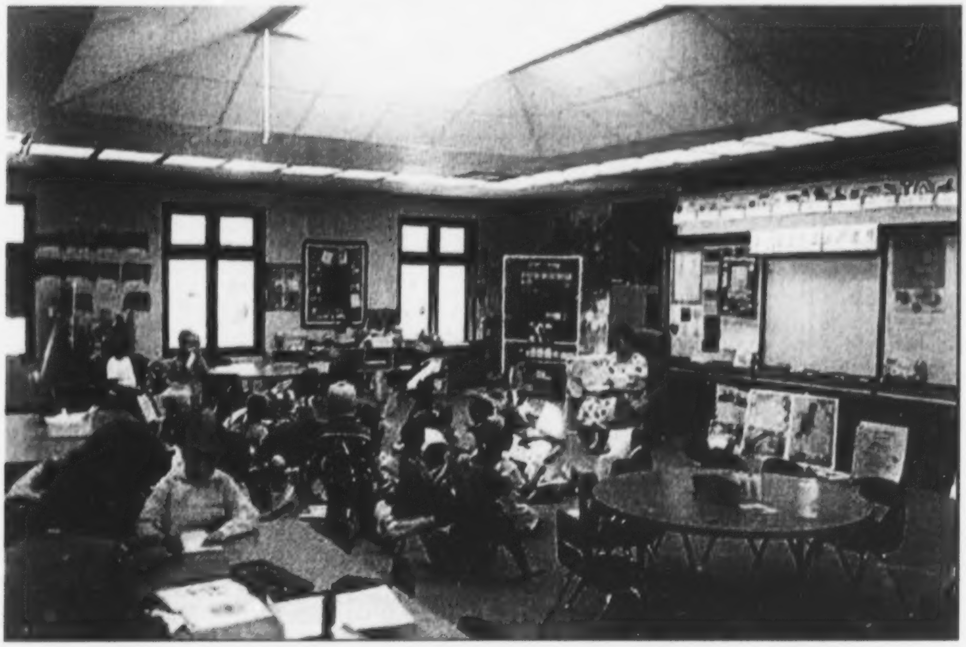
### What the Staff and Students Say

Acceptance of the integrated daylight and electric lighting scheme in these classrooms is very high. When teachers and administrators in the school were surveyed with the question, "Would you recommend using skylights in another school?", they responded very positively. On a scale of 1 to 7 (where 1 is "definitely not" and 7 is "definitely") their responses averaged 6.5!

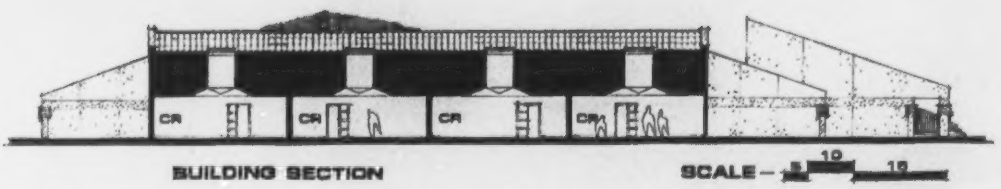
# CASE STUDY 2: THE CAPISTRANO UNIFIED SCHOOL DISTRICT

The Capistrano Unified School District is one of the fastest growing districts in Southern California. In the 1970s the District built some schools whose classrooms had few windows and were lit only with electric lights. The students complained these were "dull" and "claustrophobic." Based on these complaints, and concerns about energy efficiency and student well-being, the members of the School Board became convinced that natural light was essential for a healthy and positive classroom setting. Thus, the Board directed all architects hired to design new campuses to maximize natural lighting in the schools, using both skylights and windows. Since this Board decision in the early 1980s, the District has built nine elementary schools, five middle schools and two high schools, all of which have skylights in the classrooms. The District is very enthusiastic about its skylights. Paul Haseman, School Board Trustee for over 16 years, said:

> *"While parents tend to complain to the Board about everything in a school, I have never heard a single complaint about skylights."*



*Classroom for lower grades, with skylight at full brightness and electric lights at half power, providing 50 to 150+ footcandles around the room. Photo courtesy of PJHM Architects. All photographs reprinted with permission from Southern California Edison.*



*Section through classrooms, showing splayed ceiling and inverted pyramid diffuser. Graphic courtesy PJHM Architects.*

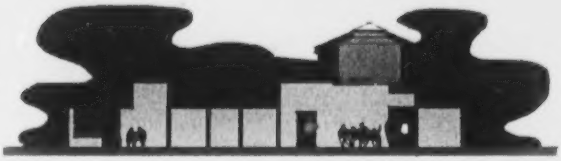
## The Skylighting System

The various architectural firms hired by the School District have experimented with a variety of skylighting configurations. Perhaps the most successful is a splayed ceiling design developed by PJHM Architects Southwest (see sidebar). An inverted plastic pyramid diffuser recessed into the splayed ceiling creates an even distribution of light, while minimizing unwanted heat gains and heat losses, and avoiding glare.

Because this diffuser sits above the plane of the ceiling, it is outside of normal vision lines in the classroom, and does not create glare. It also adds a third insulating layer to the

*Classroom for upper grades, with lights off and skylight dimmed, viewing video lesson. The dimmed skylight provides 5 to 10 footcandles around the room, excellent conditions for note-taking. Photo courtesy of PJHM Architects.*

double glazed skylights, and tends to keep any unwanted heat stratified in the insulated skylight well, where it will not add an additional load to the air-conditioning system. White gypsum board is used to create a reflective surface in the well to increase the amount of light reflected down into the classroom.



*Section through school, showing public areas with skylight highlighting a raised ceiling. Graphic courtesy PJHM Architects.*

An aluminum louver system is mounted under the 6 ft' x 6 ft rooftop skylight. The louvers, oriented east/west to control the angle of the sunlight, can be adjusted manually to reduce the amount of daylight entering the room. When the louvers are completely closed the room still receives a modest amount of daylight, about right for taking notes during a video presentation. Substitutes or new teachers often do not know how to use the louvers, but the children quickly show them.

Public areas in the schools, such as the libraries and multipurpose rooms that have higher ceilings, use a similar skylight design, but without the ceiling diffusers. Here the louvers are controlled with an electric wall switch, similar to a dimming control for lights. Again, when the louvers are completed closed, the rooms are softly lit at about 10 footcandles, sufficiently dim for theatrical or video presentations.

## Electric Lighting

Twenty recessed 2 ft x 4 ft fluorescent troffers form a 22 ft square donut of electric lights around the 14 ft x 14 ft skylight well. Prismatic lenses diffuse the light widely, providing even illumination to the classroom's bulletin board walls, which bounce light back into the center of the room. The ring of electric lights provide an additional 25–30 footcandles of light on the classroom walls during the day and an average illumination on the desktops of 50 footcandles at night.

The lighting system with two T-8 lamps and one electronic ballast per fixture uses less than 1.4 W/ft$^2$ at full power. The fixtures are on a bi-level switching system so that half of the lamps can be turned off at any time. Some classrooms also have an additional switch for lights along the front teaching wall so that the teacher's whiteboard can be specifically highlighted.

## Research Experience Pays Off

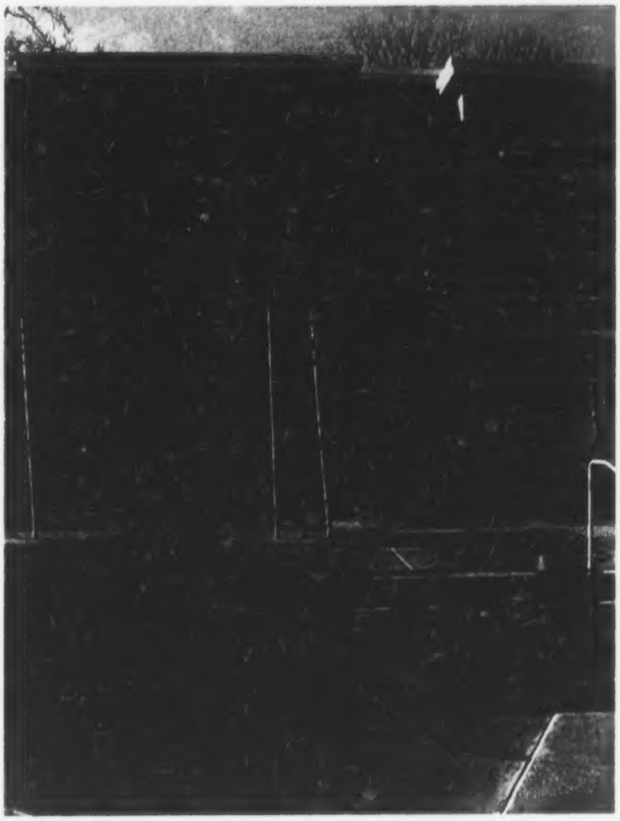
David Hansen, a senior partner at PJHM Architects Southwest, originally got involved in skylighting with a research grant sponsored by the U.S. Department of Energy during his student days at architecture school. He brought knowledge about energy efficiency and natural lighting gained from that experience back with him when he joined PJMH.

PJHM has been refining its approach ever since, adding subtle but important details, such as provisions for cleaning the inverted diffusers, or the layout of the HVAC supply and return registers that integrate with the central skylight well. They now use this skylighting design as a standard feature for all of their classroom designs, even for other school districts. PJHM architect Leo Johnson says:

> *"We strongly believe in natural lighting.*
> *We make sure that the skylights never get cut from the budget."*

# CASE STUDY 3: ROSS SCHOOL

**Ross Middle School**
**Location, Ross, CA**
**Architect: EHDD Architects**



*View of the new Middle School from the new courtyard. The windows illuminate the large hallway and gathering space for middle school students. Randy Karels, photographer*

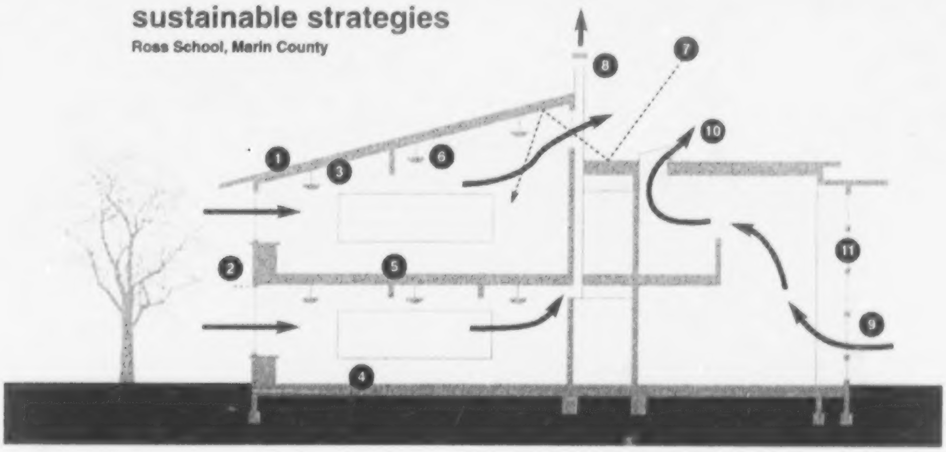
## Overview

When Ross School leadership decided to update and expand their facilities, they had two primary goals: to design a school that was both healthy for the students and cost effective for the district. Their new high performance facility achieved both.

Ross School is the sole facility in a one-school district serving 500 K-8 students. The original school was built in 1941. In 1947, the first of six additions was completed to expand capacity. Unfortunately, these additions were done haphazardly and did not make the most effective use of the 2.5-acre site. In 1996, meetings were held with school officials, community members, teachers, and parents to gather recommendations for expansion. The planning committee reviewed the input from the various stakeholders, prioritized their space requirements, and engaged the architects to complete a master plan.

Phase I of that plan includes the facilities profiled in this report. The five existing middle school classrooms were replaced with nine new classrooms on two floors with learning labs and various support spaces. All classrooms face a large, open hallway with a balcony to the upper classrooms. This space is flooded with daylight, and serves as the primary gathering place for the middle school students.

In its initial design requirements, the design committee did not request all of the high performance features included in the final design. The architects assembled engineering teams with sustainable design experience, and developed their design. They demonstrated how the design elements, such as daylighting, low VOC materials, and natural ventilation, could improve student health and performance while staying in budget. The committee agreed and supported these efforts throughout the rest of the design and construction process.


**sustainable strategies**

Ross School, Marin County

1. certified sustainably-harvested framing lumber
2. certified wood sunshades
3. plywood radiant barrier
4. radiant slab heating
5. exposed topping slab for night ventilation cooling
6. dimmable lights with daylight sensors
7. reflective white roofing
8. natural ventilation exhaust chimney
9. low ventilation intake
10. skylight ventilation exhaust
11. high-performance glazing

*High Performance features of Ross School. Courtesy EHDD Architects.*

## Thermal Comfort

The most striking feature of the mechanical design is the lack of air conditioning. The design committee had initially requested mechanical cooling, but the designers provided natural ventilation that would cool the building and save over $200,000 on an air conditioning system. In fact, natural ventilation saved enough money to pay for all of the additional high performance features.

Upper classrooms use cross-ventilation to exhaust warm air out of high clerestory windows. The lower classrooms utilize the "stack effect" to draw cool air from the windows and exhaust it through ventilation chimneys on the roof. The two-story hallway has vented

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skylights coupled with low intakes to provide air circulation. Stained concrete is the finish floor in all spaces. To improve comfort during periods of high temperatures, the windows can be kept open at night to cool the mass of the floors. During the day, the pre-cooled floors absorb heat and help keep the classrooms cool. All ventilation windows have limit stops to provide security when night ventilation is used.

Additional measures were taken to reduce heat gain. The sloped roofs have a integral radiant barrier directly applied to the underside of the exterior sheathing. Direct solar gain is reduced by shading most windows with overhangs, sunshades, or trees. All of the glazing has a visible transmittance of at least 69% and a U-factor of at least 0.3.

An under floor radiant heating system provides uniform, distributed heat with excellent comfort. The system, by itself efficient, was coupled with a new high efficiency boiler to further reduce energy needs. The system is completely silent, improving the classroom acoustics.

## Lighting and Daylighting

To improve the quality of light and reduce energy consumption, daylighting is used extensively throughout the school. Classrooms are designed with balanced daylighting supplied from two or more sides. Clerestories in the upper classrooms provide ample daylight. The white ceiling and roof maximize the available light by reflecting it into and around the classrooms. Bringing daylight into the lower level classrooms was more of a challenge, and the design does not intend to fully illuminate the spaces with daylight. Besides the exterior windows, all lower classrooms have interior windows facing the large two-story hallway. This hallway is lined with 20 ft windows to gather available light and direct as much as possible into the interior spaces.

*Interior of the upper classrooms. The upper clerestories on the right bring provide daylighting and are opened for natural ventilation. Randy Karels, photographer.*

In the classrooms, direct/indirect pendant light fixtures provide excellent light quality at low foot-candle levels. These two-lamp systems use only 1 W/ft² of electricity, and can be separately switched to cut the light in half if the teacher desires. All fluorescent lamps have low-mercury and high color rendition. To avoid over lighting the space and wasting energy, lighting systems in the upper classrooms include dimming ballasts and photo controls which are estimated to save 60% on lighting energy. Some spaces use occupancy sensors to turn off the lighting system when the rooms are unoccupied, and building-wide automatic controls shut off lighting during off hours.

Students gather between classes. Light enters the large hallway from two sides. Randy Karels, photographer.

## Indoor Air Quality

The health of the students was a primary concern, and steps were taken throughout the design to minimize the sources of indoor pollutants:

1. Building has stained concrete floors to eliminate carpet and adhesives.
2. Cabinets are made with low formaldehyde MDF board.
3. Adhesives, sealants, and clear sealers are low VOC products.
4. Interior wall and ceiling paint is "zero" VOC formulation.
5. Contractor must submit Material Safety Data Sheets (MSDS) to verify compliance with VOC specs.
6. Custodial room and toilets are directly exhausted to remove indoor pollutants.
7. Boiler has electronic ignition and sealed combustion to eliminate combustion by-products indoors.
8. Natural ventilation provides ample air changes per hour of 100% outside air.
9. Use of porous materials was limited to avoid indoor pollutants from being absorbed and re-released.
10. All fiberglass insulation is encapsulated and formaldehyde free.

## Material Efficiency

Ninety percent of the framing lumber was certified as sustainably harvested material, and glue-lam beams were used instead of large dimension timbers. These measures added less than 0.25% to the project budget, and the quality of the framing lumber was vastly superior. Sunshades and landscape benches are made from certified sustainably harvested Angico or Ipe. All pressure treated wood is ACQ or Borate treated to eliminate the chromium, copper, and arsenic present with standard CCA treatments.

Materials containing recycled elements were used throughout the building. Flyash replaced 50% of Portland cement and significantly reducing permeability and increased durability. All acoustic ceiling tile, gypsum board, insulation, and fiberboard were made with recycled content.

The building itself is designed to be recycled. Details for disassembly were added to ease maintenance, modernization, and eventual deconstruction. Roof details were designed for easy roof replacement with removable counter-flashing, and the windows can be replaced without damaging the interior or exterior finishes.

During construction, wood and cardboard recycling were required at the site. Existing two-year-old 1.6 gallons-per-minute toilets were salvaged and reinstalled. Some of the existing white boards and cabinets were also salvaged.

## Site Issues

The building was designed around three large existing oak trees, and extensive measures were taken to protect the trees during construction. The site is designed to minimize surface runoff. Most rain leaders empty directly into landscaped areas, allowing percolation back to water table while filtering out pollutants. Permeable surfaces were used on site wherever possible to reduce peak storm flows and flooding. Finally, a habitat garden in the courtyard includes native plants to minimize water use and educate students about local ecosystems.

*Substantial measures were taken to protect these oak trees next to the site. Shade from the trees and the window overhang help reduce solar gain. Randy Karels, photographer.*

## Lessons Learned

Both the designers and school officials sited early goal setting to be critical to the success of the new design. Educating the various stakeholders on the benefits of high performance design, and reaching consensus on their financial and environmental goals created a common vision, and provided structure when design decisions and compromises were discussed.

The contractor did not have any prior experience with high performance features, and care was taken to ensure that the building was built as designed. Language was included in the contractor specifications, and explained during walk-throughs, that several high performance materials (such as sustainably harvested wood, zero- VOC paints, and others) were used in the design, and no substitutions would be allowed for these elements.

Because the building was occupied in the fall of 2000, the overall effectiveness of the natural ventilation system has yet to be tested. Although certain details have yet to be finished by the contractor, such as hardware to mechanically open the clerestory windows for ventilation, the design team is confident that the ventilation system will effectively cool the space.

the
collaborative
for high
performance
schools

# High Performance Schools

# Best Practices Manual

## VOLUME II

## DESIGN

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# Volume II – Design

## High Performance Schools Best Practices Manual

Version 1.0
March 1, 2001

A Project of:

the collaborative for high performance schools

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# Preface

## Background

This is a unique period in California history. The state, already educating 1 out of every 8 students in America, has seen historical enrollment rates four times higher than national averages. Hundreds of schools a year are being built to house the 100,000 new students per year moving into the system and to accommodate state-mandated class-size reductions. The current infrastructure is aging and over 30% of existing facilities are in need of major renovation. At the same time, California schools are spending nearly $450 million per year on energy[1] in a time of rising concern over energy supplies and tight school budgets. These figures illustrate an enormous opportunity for our state's school districts to build the next generation of school facilities that improve the learning environment while saving energy, resources, and money.

The goal of this Best Practices Manual is to create a new generation of high performance school facilities in California. The focus is on public schools and levels K-12, although many of the design principals apply to private schools and higher education facilities as well. High performance schools are healthy, comfortable, energy efficient, resource efficient, water efficient, safe, secure, adaptable, and easy to operate and maintain. They help school districts achieve higher test scores, retain quality teachers and staff, reduce operating cost, increase average daily attendance (ADA), reduce liability, while at the same time being friendly to the environment.

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[1] These costs are based on data prior to the California energy crisis, which begin during the winter of 2000-2001. During this period, wholesale energy costs by a factor of eight. Eventually, some or all of these costs will be passed on to schools and other utility customers.

## Best Practices Manual Organization

This Best Practices Manual is split into three volumes:

- Volume I addresses the needs of school districts, including superintendents, parents, teachers, school board members, administrators, and those persons in the school district that are responsible for facilities. These may include the Assistant Superintendent for Facilities (in large districts), buildings and grounds committees, energy managers, and new construction project managers. Volume I aims to describe *why* high performance schools are important, *what* components are involved in their design, and *how* to navigate the design and construction process to ensure that they are built.
- Volume II contains design guidelines for high performance schools. These are tailored for California climates and are written for the architects and engineers who are responsible for designing schools as well as the project managers who work with the design teams. Volume II is organized by design disciplines and addresses specific design strategies for high performance schools.
- Volume III is the CHPS Eligibility Criteria. These criteria are a flexible yardstick that precisely defines a high performance school so that it may qualify for supplemental funding, priority processing, and perhaps bonus points in the state funding procedure. School districts can also include the criteria in their educational specifications to assure that new facilities qualify as high performance.

### CHPS Stakeholders

California Department of Education (CDE)

Coalition for Adequate School Housing (CASH)

Division of the State Architect (DSA)

Office of Public School Construction (OPSC)

California Energy Commission (CEC)

California Integrated Waste Management Board (CIWMB)

Los Angeles Department of Water and Power (LADWP)

Pacific Gas and Electric Company (PG&E)

Sacramento Municipal Utility District (SMUD)

San Diego Gas and Electric (SDG&E)

Southern California Edison (SCE)

Southern California Gas Company (SoCalGas)

California Air Resources Board (CARB)

California Department of Health Services (DHS)

Natural Resources Defense Council (NRDC)

The Best Practices Manual is supported by the CHPS website (www.chps.net), which contains research papers, support documents, databases and other information that support the Best Practices Manual.

## Who is CHPS

In November 1999, the Energy Commission called together Pacific Gas and Electric Company, San Diego Gas and Electric, and Southern California Edison to discuss the best way to improve the performance of California's schools. CHPS was formed out of this partnership and has grown to include a diverse range of government, utility, and non-profit organizations with a unifying goal: to improve the quality of education for California's children.

## Acknowledgements

A great number of people have contributed to the development of this manual. Charles Eley is the CHPS Administrator and served as the technical editor. Kathleen O'Brien and Jane Simmons (both of O'Brien

and Company) are the primary author of the chapters on materials, site planning and general conditions. Jim Benya (Benya Lighting Design) and Tom Tolen (TMT Associates) wrote the lighting chapter. Barbara Erwine (Cascadia Conservation) and Lisa Heschong (Heschong Mahone Group) are authors of the daylighting chapter. Erik Kolderup, Joe Kastner, Anamika (all of Eley Associates), and Adam Wheeler (Control Group) wrote the HVAC and mechanical chapters. Randy Karels (Eley Associates) has worked with CHPS from the beginning and coordinated and edited Volumes I and III. Deane Evans of the Sustainable Buildings Industries Council (SBIC) developed the discussion guide and prepared much of the material on cross-cutting issues.

In addition to the primary authors, Anthony Bernheim (SMWM Architects), Lynn N. Simon (Simon & Associates), and Gary Mason (Wolfe Mason Associates) serve on the CHPS Technical Advisory Group and have helped develop and review content. John Guill (Quattrocchi / Kwok Architects), Dennis Dunston (HMC Architects), Kerry Parker (TMAD Engineers) and George Wiens (WLC Architects) serve on the Professional Advisory Group, a group of architects and engineers active in the design of California schools. Both advisory groups have made significant contributions to the document and to the overall direction of CHPS.

The CHPS stakeholders have not only made the Best Practices Manual possible through their funding, they have also contributed countless hours to reviewing the document and providing direction. Special thanks to Manuel Alvarez, Gregg Ander, Chuck Angyal, Duwayne Brooks, Richard Conrad, Don Cunningham, Julia Curtis, Ray Darby, Grant Duhon, Lisa Fabula, Chip Fox, Kathy Frevert, Randall Higa, Greg Golick, Tony Hesch, Jan Johnson, Oliver Kesting, Kathleen McElroy, Daryl Mills, Bill Orr, Dana Papke, Jim Parks, Robert Pernell, Tom Phillips, Richard Sheffield, Mike Sloss, Chip Smith, Lisa Stoddard, and Jed Waldman.

# Table of Contents

**Preface** .......... **ii**
- Background .......... ii
- Best Practices Manual Organization .......... iii
- Who is CHPS .......... iii
- Acknowledgements .......... iii
- Table of Contents .......... v

**Volume II – Design** .......... **1**
- Guidelines for High Performance Schools .......... 1

**Introduction to the Guidelines** .......... **2**
- The Design Process .......... 2
- Integrated Design .......... 3
- Goals and Cross-cutting Issues .......... 5
- Commissioning .......... 19
- CHPS Eligibility Criteria .......... 20
- Material Selection and Research .......... 21
- General Purpose Design and Evaluation Tools .......... 24
- Anatomy of a Guideline .......... 25
- Climates .......... 27

**General Conditions** .......... **28**
- Overview .......... 28
- Guideline GC1: Sustainable Job-site Management .......... 31
- Guideline GC2: Construction and Demolition (C&D) Waste Management .......... 33
- Guideline GC3: Indoor Air Quality During Construction .......... 37
- Guideline GC4: Site Protection During Construction .......... 40
- Guideline GC5: Contractor's Commissioning Responsibilities .......... 43

**Site Planning** .......... **46**
- Overview .......... 46
- Guideline SP1: Optimum Building Orientation .......... 55
- Guideline SP2: Landscaping to Provide Shade to Buildings and Paved Areas .......... 58
- Guideline SP3: Safe and Energy Efficient Transportation .......... 60
- Guideline SP4: Landscape Design & Management .......... 62
- Guideline SP5: Impervious Surfaces .......... 66
- Guideline SP6: Drought Tolerant and Pest-Resistant Plants .......... 72
- Guideline SP7: Location of HVAC Equipment .......... 75
- Guideline SP8: Landscaping Accessories .......... 77
- Guideline SP9: Landscaping Soil, Amendments and Mulch .......... 79
- Guideline SP10: Water-Efficient Irrigation Systems .......... 82
- Guideline SP11: Stormwater Management and Drainage Materials .......... 85
- Guideline SP12: Reclaimed Water for Irrigation .......... 88
- Guideline SP13: Integrated Weed, Disease and Pest Management .......... 91
- Guideline SP14: Groundwater Management .......... 94
- Guideline SP15: On-Site Wastewater Treatment .......... 97

**Interior Surfaces and Furnishings** .......... **100**
- Overview .......... 100
- Guideline IS1: Carpeting .......... 112
- Guideline IS2: Resilient Flooring .......... 117
- Guideline IS3: Ceramic Tile / Terrazzo .......... 120

Guideline IS4: Concrete Flooring ........ 123
Guideline IS5: Wood Flooring ........ 125
Guideline IS6: Bamboo Flooring ........ 128
Guideline IS7: Gypsum Board ........ 130
Guideline IS8: Concrete Masonry ........ 132
Guideline IS9: Acoustical Walls and Ceilings ........ 135
Guideline IS10: Paints and Coatings ........ 138
Guideline IS11: Casework and Trim ........ 141
Guideline IS12: Interior Doors ........ 144
Guideline IS13: Toilet Partitions ........ 146

**Electric Lighting and Controls ........ 148**

Overview ........ 148
Guideline EL1: Pendant Mounted Lighting ........ 168
Guideline EL2: Recessed Lighting ........ 171
Guideline EL3: Surface Mounted Lighting ........ 174
Guideline EL4: Lighting Controls for Classrooms ........ 177
Guideline EL5: Gym Lighting ........ 180
Guideline EL6: Corridor Lighting ........ 184
Guideline EL7: Lighting for A Multi-Purpose Room ........ 187
Guideline EL8: Lighting for A Library or Media Center ........ 191
Guideline EL9: Lighting for Offices and Teacher Support Rooms ........ 195
Guideline EL10: Lighting for Locker and Toilet Rooms ........ 197
Guideline EL11: Outdoor Lighting ........ 200

**Daylighting and Fenestration Design ........ 204**

Overview ........ 205
Guideline DL1: View Windows ........ 222
Guideline DL2: High Sidelighting—Clerestory ........ 226
Guideline DL3: High Sidelighting—Clerestory with Light Shelf or Louvers ........ 230
Guideline DL4: Classroom Daylighting—Wall Wash Top Lighting ........ 234
Guideline DL5: Central Toplighting ........ 238
Guideline DL6: Patterned Toplighting ........ 242
Guideline DL7: Linear Toplighting ........ 245
Guideline DL8: Tubular Skylights ........ 248

**Building Enclosure and Insulation ........ 251**

Overview ........ 251
Guideline IN1: Wall Insulation ........ 263
Guideline IN2: Roof Insulation ........ 266
Guideline IN3: Cool Roofs ........ 269
Guideline IN4: Radiant Barriers ........ 273
Guideline IN5: Reduce Infiltration ........ 276

**HVAC ........ 279**

Overview ........ 279
Guideline TC1: Cross Ventilation ........ 295
Guideline TC2: Stack Ventilation ........ 301
Guideline TC3: Ceiling Fans ........ 305
Guideline TC4: Gas/Electric Split System ........ 309
Guideline TC5: Packaged Rooftop System ........ 314
Guideline TC6: Displacement Ventilation System ........ 318
Guideline TC7: Hydronic Ceiling Panel System ........ 321
Guideline TC8: Unit Ventilator System ........ 326
Guideline TC9: Ductless Split System ........ 329
Guideline TC10: Evaporative Cooling System ........ 332

Guideline TC11: VAV Reheat System ..... 335
Guideline TC12: Radiant Slab System ..... 339
Guideline TC13: Baseboard Heating System ..... 343
Guideline TC14: Gas-Fired Radiant Heating System ..... 346
Guideline TC15: Evaporatively Precooled Condenser ..... 348
Guideline TC16: Dedicated Outside Air Systems ..... 350
Guideline TC17: Economizers ..... 352
Guideline TC18: Air Distribution Design Guidelines ..... 355
Guideline TC19: Duct Sealing and Insulation ..... 360
Guideline TC20: Hydronic Distribution ..... 362
Guideline TC21: Chilled Water Plants ..... 366
Guideline TC22: Hot Water Supply ..... 373
Guideline TC23: Adjustable Thermostats ..... 379
Guideline TC24: EMS/DDC ..... 381
Guideline TC25: Demand Controlled Ventilation ..... 385
Guideline TC26: CO Sensors for Garage Exhaust Fans ..... 387

**Other Equipment and Systems ..... 389**
Overview ..... 389
Guideline OS1: Photovoltaics ..... 391
Guideline OS2: Solar Pool Heating ..... 397
Guideline OS3: Rainwater Collection Systems ..... 402
Guideline OS4: Gray Water Systems ..... 408
Guideline OS5: Timers for Recirculating Hot Water Systems ..... 413
Guideline OS6: Efficient Terminal Devices ..... 416
Guideline OS7: Waterless Urinals ..... 418
Guideline OS8: Relocatable Classrooms ..... 421

# Volume II – Design

## Guidelines for High Performance Schools

This is **Volume II** of the Best Practices Manual for California High Performance Schools. It is written for architects and engineers who are responsible for designing schools, and for the project managers who work with the design teams. The design strategies presented in Volume II are organized according to eight design disciplines: general conditions; site planning; interior surfaces and furnishings; electric lighting and controls; daylighting and fenestration; building enclosure and insulation; HVAC (heating, ventilating and air-conditioning); and other equipment and systems. Applying these guidelines will result in schools that are healthy, comfortable, energy efficient, resource efficient, water efficient, safe, secure, adaptable and easy to operate and maintain.

Overall, the CHPS Best Practices Manual is organized in three volumes, each with a specific purpose and directed toward the needs of a specific audience. Volume I of the Best Practices Manual addresses the needs of school districts, and is written in particular for those persons in the school district who are responsible for facilities. Volume III contains criteria for high performance schools.

# INTRODUCTION TO THE GUIDELINES

## The Design Process

The characteristics of a high performance school are outlined in Volume I, and reflect a mix of environmental, economic and social objectives. The design process used to achieve high performance schools is fundamentally different from conventional practice. To be most effective, this process requires a significant commitment on the part of design professionals to:

- Meet environmental performance criteria.
- Maintain a view of the building and site as a seamless whole within the context of its community.
- Work with the understanding that the building exists within the context of a natural ecosystem even when the setting is urban.
- Incorporate interdisciplinary collaboration throughout the design and construction process.
- Integrate all significant building design decisions and strategies—beginning no later than the programming phase.
- Optimize design choices through simulations, models or other design tools.
- Employ life cycle cost analysis in all decision making.
- Commission all building equipment and systems to assure continued optimum performance.
- Document high performance materials in the building so that maintenance and repairs can be made in accordance with the original design intent.
- Encourage sustainable construction operations and building maintenance.
- Provide clear guidance, documentation, and training for operations and maintenance staff.

The typical design process for schools begins with programming and selection of the architectural-engineering team. It then proceeds through schematic design, design development, contract documents, construction, commissioning and occupancy. The sooner high performance goals are considered in the design process, the easier and less costly they are to incorporate. Many of the guidelines presented in this document must be considered early in the design process in order for them to be successful. Figure 1 shows a timeline through the design process and indicates the types of measures and design strategies that can be considered along the way.

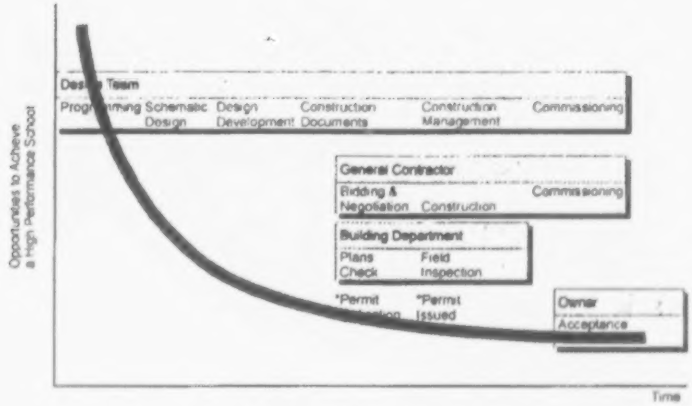

*Figure 1 – Opportunities in the Design Process*

Volume I outlines the characteristics of a high performance school. In Volume II, these characteristics are described in more detail in the discussion of Goals and Cross-cutting Issues. For best results, these high performance goals should be reflected in all aspects of project documentation. High performance goals established during programming should be clearly stated in the educational specifications, the request for proposals (RFP) to select the design team, in the instruction to bidders, and as part of the project summary. These goals are best expressed in terms of performance. The CHPS Eligibility Criteria in Volume III have these goals clearly formulated so that they can be appropriately referenced.

## Integrated Design

Integrated design is the consideration and design of all building systems and components together. It brings together the various disciplines involved in designing a building and reviews their recommendations as a whole. It recognizes that each discipline's recommendations have an impact on other aspects of the building project. This approach allows for optimization of both building performance and cost. Too often, HVAC systems are designed independently of lighting systems, for example, and lighting systems are designed without consideration of daylighting opportunities. The architect, mechanical engineer, electrical engineer, contractors, and other team members each have their scope of work and often pursue it without adequate communication and interaction with other team members. This can result in oversized systems or systems that are optimized for non-typical conditions.

Even a small degree of integration provides some benefits. It allows professionals working in various disciplines to take advantage of efficiencies that are not apparent when they are working in isolation. It can also point out areas where trade-offs can be implemented to enhance resource efficiency. Design integration is the best way to avoid redundancy or conflicts with aspects of the building project planned by others.

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The earlier that integration is introduced in the design process, the greater the benefit. For a high performance school, project team collaboration and integration of design choices should begin no later than the programming phase. In addition, the project team is likely to be more broadly defined than in the past, and may include energy analysts, materials consultants, lighting designers, life cycle cost consultants and commissioning agents. Design activities may expand to include charrettes, modeling exercises and simulations.

This manual provides details and implementation rules for individual design strategies. As you read about the individual strategies, please do not lose sight of the fact that whole building performance is what matters.

## Goals and Cross-cutting Issues

Volume II is organized into eight technical chapters that correspond to the major disciplines in the building design process. The guidelines presented in each chapter are directed toward building schools that achieve the following goals, which are issues that cut across each of the major disciplines:

- Health and Indoor Air Quality
- Thermal Comfort
- Visual Comfort
- Acoustic Comfort
- Security and Safety
- Ecosystem Protection
- Energy Efficiency
- Water Efficiency
- Materials Efficiency
- Buildings as a Teaching Tool

Table 1 shows which of the goals (or cross-cutting issues) apply to each of the technical chapters. The rest of this section describes these relationships in more detail and provides checklists that summarize the key high performance design strategies for each discipline.

Table 1 – Relationship Between Goals and Technical Chapters

| | Goals/Cross-cutting Issues | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Technical Chapters | Health and Indoor Air Quality | Thermal Comfort | Visual Comfort | Acoustic Comfort | Security and Safety | Ecosystem Protection | Energy Efficiency | Water Efficiency | Materials Efficiency | Building as a Teaching Tool |
| General Conditions | ✓ | | | | ✓ | ✓ | ✓ | ✓ | ✓ | |
| Site Planning | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Interior Surfaces and Furnishings | ✓ | | | ✓ | | ✓ | ✓ | | ✓ | ✓ |
| Electric Lighting and Controls | | ✓ | ✓ | | | | ✓ | | | ✓ |
| Daylighting and Fenestration | | ✓ | ✓ | | ✓ | | ✓ | | ✓ | ✓ |
| Building Enclosure | | ✓ | | ✓ | | | ✓ | | ✓ | |
| Heating, Ventilating and Air-conditioning (HVAC) | ✓ | ✓ | | ✓ | ✓ | | ✓ | ✓ | ✓ | ✓ |
| Other Equipment and Systems | | | | | | | ✓ | ✓ | ✓ | ✓ |

## Health and Indoor Air Quality

The quality of the air inside a school is critical to the health and performance of children, teachers and staff. A high performance school should provide superior quality indoor air by: eliminating and controlling the sources of contamination; providing adequate ventilation; preventing unwanted moisture accumulation; and implementing effective operations and maintenance procedures.

According to the U.S. EPA, the concentration of pollutants inside a building may be two to five times higher than outside levels. Children are particularly vulnerable to such pollutants because their breathing and metabolic rates are high relative to their size. Maintaining a high level of indoor air quality is therefore critical for schools. Failure to do so may, according to the EPA, can negatively impact student and teacher performance; increase the potential for long and short term health problems for students and staff, increase absenteeism, accelerate deterioration and reduce efficiency of the school's physical plant, create negative publicity that could damage a school's image, and create potential liability problems.

*Boscawen Elementary School, Boscawen, NH*

*This 53,000-square-foot, 420-student school north of Concord, New Hampshire is the first in the country to use a combined displacement and demand-control ventilation system to provide superior indoor air quality and thermal comfort with reduced overall energy costs.*

*In this system, students and teachers are constantly surrounded by fresh air. Stale air rises above them and is then vented out. None of it is recirculated. The result is a school with exemplary indoor air quality that is, at the same time, energy and cost efficient.*

*As Dr. G.W. Porter of the New Hampshire State Department of Education notes, "Despite the innovative engineering, its cost was equal, or possibly less then, other typical schools. Maintenance costs, such as heating, are expected to be lower; and even without air-conditioning, the building will be even cooler in spring and fall. Air quality, a problem that's plagued a number of our schools, will also be vastly improved."*

To eliminate or control contamination, select materials that are low emitters of substances such as VOCs or toxins. Some of these building materials may be unfamiliar to custodial staff, so provide training to the staff, and select durable products and avoid products that unnecessarily complicate maintenance and operations. Any material can affect the acoustic and visual quality of a school; be sure to consider this when evaluating these materials. The following checklist summarizes strategies improve a school's indoor air quality.

### Health and Indoor Air Quality Checklist

**Eliminate or control contamination at the source**

- ✓ *Require a construction IAQ plan.*
- ✓ *Test the site for sources of contamination such as radon, hazardous waste, or fumes from nearby industrial or agricultural uses.*
- ✓ *Locate sources of exhaust fumes (e.g., from vehicles) away from air intake vents.*
- ✓ *Consider recessed grates, "walk off" mats and other techniques to reduce dirt entering the building.*

**Avoid materials that contaminate indoor air**

- ✓ *Use adhesives and sealants with low VOC levels, and paints and coatings that meet or exceed Green Seal's VOC and chemical component limits.*
- ✓ *Specify carpet systems that meet or exceed the Carpet and Rug Institute's Green Label IAQ Test Program.*
- ✓ *Specify composite wood or agrifiber products containing no urea-formaldehyde resins.*

**Provide adequate ventilation**

- ✓ *Allow adequate time for installed materials and furnishings to "off-gas" before the school is occupied. Run the HVAC system continuously at the highest possible outdoor air supply setting for at least 72 hours after all materials and furnishings have been installed.*
- ✓ *Design the ventilation system to provide a minimum of 15 cubic feet/minute/person of filtered outdoor air to all occupied spaces. Consider 20 cubic feet/minute/person.*
- ✓ *Ensure that ventilation air is effectively delivered to and distributed through the rooms in a school.*
- ✓ *Provide local exhaust for restrooms, kitchens, labs, janitor's closets, copy rooms and shop rooms.*

**Prevent unwanted moisture accumulation**

- ✓ *Design the ventilation system to maintain the indoor relative humidity between 30% and 50%.*
- ✓ *Design to minimize water vapor condensation, especially on walls, the underside of roof decks, and around pipes or ducts.*
- ✓ *Design to keep precipitation out of the building, off the roof and away from the walls.*

**Operate and maintain the building effectively**

- ✓ *Regularly inspect and maintain the ventilation system so that it continues to operate as designed.*
- ✓ *Install $CO_2$ sensors in large assembly areas for real-time monitoring of air quality.*
- ✓ *Minimize the use of toxic cleaning materials.*
- ✓ *Use EPA's "Indoor Air Quality—Tools for Schools" to guide the operations and maintenance process.*

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## Thermal Comfort

Thermal comfort is an important variable in student and teacher performance. Hot, stuffy rooms—and cold, drafty ones—reduce attention spans and limit productivity. They also waste energy, adding unnecessary cost to a school's bottom line. Excessively high humidity levels can also contribute to mold and mildew. Thermal comfort is primarily a function of the temperature and relative humidity in a room, but air speed and the temperature of the surrounding surfaces also affect it. A high performance school should ensure that rooms and HVAC systems are designed to allow temperature and humidity levels to remain within the "comfort zone" at all points in an occupied space. Thermal comfort guidelines are provided in the technical chapter on heating, ventilating and air-conditioning systems (HVAC).

*The Advantage Classroom™*

*The Advantage Classroom is a design concept developed by The H. L. Turner Group in Concord, NH. Among other attributes, the Advantage Classroom provides superior thermal comfort through a design approach that combines low velocity ventilation, room air stratification, and dehumidification cooling. This approach, which has been applied at more than 20 school in New England, reduces drafts and "hot spots," enhances efficiency and control by including thermostats in each room, reduces room noise, and ensures optimal temperature and humidity levels by ongoing monitoring of room conditions.*

*Kim Cheney, a teacher at one school built with Advantage Classrooms, is very satisfied with the results: "Everything about it is incredible; the whiteboards eliminate chalk dust, the air is clean, the temperature is perfect, it's all so comfortable. In the old school . . . we'd be really cold, but if you turned on the heat it would get so hot the students would get tired in the afternoon. In moving into the new school we went from the 19th century straight to the 21st."*

Thermal comfort is strongly influenced by how a specific room is designed (for example, the amount of heat its walls and roof gain or lose, the amount of sunlight its windows let in, whether the windows can be opened) and by how effectively the HVAC system can meet the specific needs of that room. Balancing these two factors—room design and HVAC system design—is a back-and-forth process that continues throughout all the stages of developing a new facility. In a high performance school, the process ends with an optimal blend of both components: rooms configured for high student and teacher productivity served by an energy-efficient HVAC system designed, sized and controlled to maintain thermal comfort under all conditions.

### Thermal Comfort Checklist

**Design in accordance with ASHRAE standards**

- ✓ *Design systems to provide comfort in accord with American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE) Standard 55–1992 (with 1995 Addenda) Thermal Environmental Conditions for Human Occupancy.*
- ✓ *When a design incorporates natural ventilation (e.g., operable windows to provide direct outdoor air during temperate weather), consider adjusting the requirements of ASHRAE Standard 55–1992 to account for the impact.*

**Install controls and monitor system performance**

- ✓ *Install controls in each classroom to give teachers direct control over thermal comfort. Evaluate the potential impact of such controls on the overall efficiency of the HVAC system.*
- ✓ *Consider providing a temperature and humidity monitoring system to ensure optimal thermal comfort performance.*
- ✓ *Consider including temperature and humidity monitoring as part of the building's overall energy management system.*

**Analyze room and system layouts**

- ✓ *Analyze room configurations and HVAC distribution layouts to ensure all parts of a room are receiving adequate ventilation.*
- ✓ *Analyze placement of windows and skylights and provide adequate, controllable shading to avoid "hot spots" caused by direct sunlight.*

### Visual Comfort

Performing visual tasks is a central component of the learning process for both students and teachers. A high performance school should provide a rich visual environment—one that enhances, rather than hinders, learning and teaching—by carefully integrating natural and electric lighting strategies; by balancing the quantity and quality of light in each room; and by controlling or eliminating glare.

Students spend much of their day engaged in visual tasks—writing, reading printed material, reading from visual display terminals, or reading from blackboards, whiteboards and overheads. They must constantly adjust their vision from "heads up" to "heads down" position and back again. Inadequate lighting and/or glare can seriously affect a student's ability to learn. On the other hand, a comfortable, productive visual environment—one that takes into account more than simply the amount of light hitting the desktop—will enhance the learning experience for both students and teachers.

*Durant Road Middle School, Wake County, NC*

*Daylighting and electric lighting are seamlessly integrated in this 1300-student school in Raleigh, North Carolina. The design team repeatedly analyzed the interactions between the size and location of the roof monitors; the size and configuration of the electric lighting fixtures; the color and reflectance of the walls, floor and ceiling; and the amount of light hitting the desks.*

*"We worked the problem using computer simulation tools until we had just the right combination. The result is a group of classrooms that are bright, fun places to be; that rely on natural sunlight for the bulk of their lighting needs; that virtually eliminate glare; and that save the school money on energy; all at the same time," notes Mike Niklas, chief architect for the project.*

*Because of the school's exceptional daylit design it was featured on CNN's "Science and Technology Week" series.*

Visual comfort results from a well designed, well integrated combination of natural and artificial lighting systems. Any strategy for enhancing the visual environment will therefore strongly affect the size and configuration of both these systems (for example, number, type and placement of windows; number, type and placement of light fixtures; etc.). The final configurations will, in turn, affect a school's HVAC systems.

An optimized overall design will provide a high quality luminous environment and will use daylight effectively to reduce the need for artificial lighting. Less artificial lighting means lower electricity bills and less waste heat which, in turn, means less demand for cooling and lower HVAC operating expenses.

#### Visual Comfort Checklist

**Integrate natural and artificial lighting strategies**

- ✓ *Take the amount of daylight entering a room into account when designing and sizing the artificial lighting system for that room.*
- ✓ *Provide controls that turn off lights when sufficient daylight exists.*
- ✓ *Consider dimming controls that continuously adjust lighting levels to respond to daylight conditions.*

**Balance the quantity and quality of light in each room**

- ✓ *Avoid excessively high horizontal light levels.*
- ✓ *Use the newly revised 9th edition of the IESNA's* Lighting Handbook: Design and Application *as a guide.*
- ✓ *Design for "uniformity with flexibility."*
- ✓ *Illuminate spaces as uniformly as possible, avoiding shadows or sharp distinctions between dark and light.*
- ✓ *Provide task or accent lighting to meet specific needs (e.g., display areas, whiteboards, team areas).*
- ✓ *Develop individual lighting strategies for individual rooms or room types (e.g., classrooms, hallways, cafeteria, library, etc.). Avoid "one size fits all" approaches.*

**Control or eliminate glare**

- ✓ *Consider how light sources in a room will affect work surfaces. Design to avoid direct glare (from sources in front or to the side of a work area); overhead glare (from sources above the work area); and reflected glare (from highly reflective surfaces, including glossy paper and computer terminals).*
- ✓ *Consider increasing the brightness of surrounding surfaces, decreasing the brightness of light sources, or both as control methods.*
- ✓ *Consider interior (shades, louvers, blinds) or exterior (overhangs, trees) strategies to filter daylight and control glare from sunlight.*

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## Acoustic Comfort

Parents, students, teachers and administrators across the country are increasingly concerned that classroom acoustics are inadequate for proper learning. Noise from outside the school (from vehicles and airplanes, for example), hallways (foot traffic and conversation), other classrooms (amplified sound systems and inadequate sound transmission loss), mechanical equipment (compressors, boilers and ventilation systems), and even noise from inside the classroom itself (reverberation) can hamper students' concentration.

*Sterling Montessori Academy, Morrisville, NC YES*

***The roof monitors that bring daylight into the classrooms of this 200-student, elementary school in a Raleigh suburb provides an added benefit: improved acoustics. The large, open space under the monitors, plus the baffles used to control glare, help dampen sound throughout the classroom. The result is an improved environment for teaching and learning.***

***A teacher at the school, when asked to name the best feature of her new classroom, unhesitatingly said the great acoustics, surprising the architects who had expected the large amounts of daylight to be the answer. Happily, the roof monitors provide both.***

Trying to hear in a poor acoustical environment is like trying to read in a room with poor lighting: stress increases, concentration decreases, and learning is impaired. This is especially true for younger students (the ability to sort meaningful sounds from noise is not fully developed until children reach their teens); those for whom English is a second language; and those with hearing impairments. Although little consideration has historically been given to acoustic design in classrooms—as opposed to lighting and ventilation—this situation is beginning to change. The information and tools needed to design classrooms for high acoustical performance now exist. They can be used to ensure that any newly constructed classroom provides an acoustic environment that positively enhances the learning experience for students and teachers.

### Acoustic Comfort Checklist

**Ensure a superior acoustical environment**

- ✓ *Reduce sound reverberation time inside the classroom.*
- ✓ *Limit transmission of noise from outside the classroom.*
- ✓ *Minimize background noise from the building's HVAC system.*

## Security and Safety

Safety and security have become critical concerns for students, teachers and parents across the country. A high performance school should create a safe and secure environment by design. Opportunities for natural surveillance should be optimized; a sense of territoriality should be reinforced; access should be controlled; and technology should be used to complement and enhance, rather than substitute for, a facility's security-focused design features.

*Boscawen Elementary School, Boscawen, NH*

*"Room like," non-institutional corridors, plenty of views out and in, and windows between the classrooms and the hallway, all combine to improve the safety and sense of security in this southern New Hampshire school.*

Crime and vandalism—and the fear they foster—are problems facing school populations throughout the United States. While better buildings alone cannot solve these problems, they can be powerful factors in helping reduce crime and other antisocial behavior. Thoughtful design that builds on basic CPTED (Crime Prevention through Environmental Design) principles is the key.

Security-based design strategies will influence a school's basic layout and site plan. If properly integrated from the beginning of the development process, these influences will complement and enhance other high performance design strategies used in the facility. For example, daylit classrooms can "share" their natural light with adjacent corridors through windows or glass doors provided primarily for surveillance purposes. This "free" natural light can, in turn, be used to offset the need for artificial lighting in the corridors. Security technology strategies will not strongly impact other systems in the school, unless they are incorporated into a comprehensive automated control system for the whole facility.

### Security and Safety Checklist

**Increase opportunities for natural surveillance**

- ✓ *Design landscaping to minimize places that are hidden from view. Ensure that key areas—parking, bicycle storage, drop-off points, play equipment, entries—are easily observable from inside the building.*
- ✓ *Design exterior lighting to facilitate nighttime surveillance.*
- ✓ *Consider providing views through glazed doors or windows from classrooms into circulation corridors.*
- ✓ *Design to minimize areas within the building that are hidden from view.*
- ✓ *Consider open stairwells.*

**Reinforce a sense of territoriality**

- ✓ *Foster a sense of "ownership" of the school by students and teachers by clearly defining borders—what is part of the school and what is not.*
- ✓ *Consider decorative fencing and special paving treatments to delineate the boundaries of the school grounds.*
- ✓ *Consider designing common areas, particularly corridors, so that are less institutional and more "room like."*

**Design for easy maintenance**

- ✓ *Consider graffiti-resistant materials and finishes.*

**Control access to the building and grounds**

- ✓ *Consider decorative fencing to control access to school grounds.*
- ✓ *Limit the number of entries to the building. Allow visual surveillance of all entries from inside the school.*
- ✓ *Provide capability to "lock down" parts of the school when the facility is used for after-hours activities.*

**Integrate security technology**

- ✓ *Consider incorporating interior and exterior surveillance cameras.*
- ✓ *Ensure that all high-risk areas (office, cafeteria, shops, labs, etc.) are protected by high security locks.*
- ✓ *Consider metal detectors and other security technologies as appropriate.*

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### Ecosystem Protection

A high performance school protects the natural ecosystem. As much as possible, the school incorporates products and techniques that do not introduce pollutants or degradation at the project site or at the site of extraction, harvest or production. Give preference to materials that are locally extracted or harvested and locally manufactured to eliminate potential air pollution due to petroleum-based transportation.

Some of these building materials may be unfamiliar to custodial staff. Avoid products that unnecessarily complicate maintenance and operations procedures, and provide training to ensure proper upkeep and ensure full service life. When evaluating materials, be sure to consider their impact on the acoustic and visual quality of a school.

> *Sakai Intermediate School, Bainbridge Island, Washington*
>
> *This new facility is an excellent example of a school project that went the extra mile to protect the natural environment. The building and sports field's footprint was reduced to increase a buffer zone far beyond required to protect an adjacent wetland and salmon stream. A culvert that blocked salmon passage was removed. A system separating groundwater from stormwater allowed the groundwater to recharge the natural wetland, and allowed designers to reduce the size of the stormwater retention pond.*
>
> *Students and other community members were involved in restoring the salmon stream and building an outdoor classroom platform, and they acted as tour guides for the open house explaining the special site protection features.*

High performance school design is environmentally responsive to the site, incorporating natural conditions such as wind, solar energy, and moisture to enhance the building's performance. Natural features and areas of the site should be preserved; damaged areas should be restored. Take steps to eliminate stormwater runoff and erosion that can affect local waterways and adjacent ecosystems.

The use of these strategies can help teach students about the importance of protecting natural habitats and the impact of human activities on ecological systems.

#### Ecosystem Protection Checklist

**Specify indigenous materials**

- ✓ *Specify materials appropriately adapted for the building and site, such as native landscaping and locally extracted building materials.*

**Specify wood products that are harvested sustainably**

- ✓ *Consider a goal of having 50% of the school's wood-based materials certified in accordance with the Forest Stewardship Guidelines for wood-based components.*

**Avoid materials that harm the ecosystem**

- ✓ *Eliminate materials that harm the natural ecosystem through toxic releases or by producing unsafe concentrations of substances.*
- ✓ *Eliminate the use of ozone-depleting chlorofluorocarbons (CFCs) and hydrochlorofluorocarbons (HCFCs) as refrigerants in all HVAC systems.*
- ✓ *Give preference to locally manufactured materials and products to eliminate air pollution due to transportation.*
- ✓ *Eliminate products that pollute water, air or other natural resources where they are extracted, manufactured, used, or disposed of.*
- ✓ *Evaluate the potential impact of specified site materials on natural ecosystems located on site or adjacent to the site.*

**Preserve and restore natural features and areas on the site and nearby**

- ✓ *During construction, develop and implement a construction operations plan to protect the site.*
- ✓ *Develop the site to prevent stormwater runoff and erosion.*
- ✓ *Restore damaged natural areas.*
- ✓ *Maintain connection to nearby natural ecosystems.*

### Energy Efficiency

Energy-efficient schools cost less to operate, which means that more money can be used for books, computers, teacher salaries and other items essential to the educational goals of schools. Energy-efficient schools also reduce emissions to the environment, since energy use is related to emissions of carbon dioxide ($CO_2$), sulfur oxides ($SO_x$), nitrous oxides ($NO_x$) and other pollutants. Smaller air conditioners also reduce the likelihood of ozone-depleting gases escaping to the atmosphere. All the technical chapters and guidelines in Volume II relate to energy efficiency is some meaningful way. By following the guidelines in this manual, energy use can be reduced by up to 40% compared to conventional buildings that minimally comply with the California's Energy Efficiency Standards for Residential and Nonresidential Buildings (Title 24).

Guidelines explicitly related to energy efficiency are provided in five of the technical chapters: electric lighting, daylighting and fenestration, building enclosures, HVAC systems, and other equipment and systems. The key issues are summarized below.

### Electric Lighting

Lights have two bulbs that are separately switched, so that half the lamps can be turned off at one time, further reducing energy consumption. Some lights are also tied to occupancy sensors so that they automatically turn off when a room is unoccupied. Finally, the entire lighting system is on a timer to ensure all lights are shut off at night. These features, combined with daylighting, create a total system that delivers high quality lighting that is energy and cost efficient. Architect Scott Shell hopes that these features, "...will not only make the school a better place for teaching and learning, but will also be used as tools that help make children more aware of how buildings and their use of energy impact the environment." Electric lighting can account for 30 to 50% of a school's electric power consumption. Even modest efficiency improvements can mean substantial bottom-line savings.

*Ross Middle School, Ross, CA*

*This new, 200-student facility north of San Francisco incorporates a full range of high performance electric lighting features. Direct/indirect pendant luminaires provide high quality light at low footcandle levels. In the daylit classrooms, dimming ballasts and photosensors are also used, so light output can very depending daylight availability. Used property, this strategy alone can save up to 60% of the electrical energy needed for lighting these rooms.*

Electric lighting systems interact closely with a school's daylighting and HVAC systems. Daylighting strategies that are well integrated with lighting equipment and controls will reduce the demand for electric light. This lower demand, if it is met by a combination of high efficiency electric lighting equipment and controls, can substantially lower a school's electricity usage.

An added benefit: more efficient lighting produces less waste heat, reducing need for cooling and further reducing operating costs. Cooling equipment can be downsized, resulting in first cost and operating cost savings to the school.

These savings are achievable now—in any school—using readily available equipment and controls.

### Energy Efficiency Checklist for Electric Lighting

**Design for high efficiency and visual comfort**

- ✓ *Develop individual lighting designs for individual rooms or room types (classrooms, hallways, cafeteria, etc.). Avoid overlighting any space.*
- ✓ *Consider a mix of direct and indirect light sources for each design.*
- ✓ *Optimize each design so that overall lighting levels ("watts per square foot") are as low as possible while still providing optimal task illumination.*
- ✓ *Analyze the impact of the lighting system on the HVAC system and resize the HVAC system as appropriate.*
- ✓ *Design systems to facilitate cleaning/lamp replacement.*

**Specify high efficiency lamps and ballasts**

- ✓ *Use T-8 fluorescent lamps with electronic ballasts for most general lighting applications (classrooms, offices, multipurpose rooms, cafeterias). Consider using T-5 lamps if justified by life-cycle cost.*
- ✓ *Consider dimmable ballasts, especially in daylit rooms.*

**Optimize the number and type of luminaires**

- ✓ *Use suspended indirect or direct/indirect luminaires in classrooms to provide soft uniform illumination.*
- ✓ *Consider using additional accent and directional task lighting for specific uses (such as display areas).*
- ✓ *Consider using a smaller number of higher efficiency luminaires to light specific spaces, resulting in fewer fixtures to purchase, install, maintain and clean.*

**Incorporate controls to ensure peak system performance**

- ✓ *Use occupancy sensors with manual overrides to control lighting (on-off) in classrooms, offices, restrooms and other intermittently occupied spaces. Consider scheduled dimming and/or time clocks in other rooms.*
- ✓ *Consider incorporating lighting controls into the facility's overall energy management system.*

**Integrate electric lighting and daylighting strategies**

- ✓ *Treat the electric lighting system as a supplement to natural light. Design for daylighting first and use the electric system to add light as needed during the day and provide sufficient illumination at night.*
- ✓ *Provide controls to dim or turn off lights at times when daylight is sufficient. Consider photoelectric controls that are sensitive to levels of daylight.*
- ✓ *Consider controls that provide continuous, rather than stepped, dimming.*

## Daylighting and Fenestration Design

Daylighting is the controlled admission of natural light into a space through windows, skylights or roof monitors. A high performance school should use as much daylight as possible, especially in classrooms, while avoiding excessive heat loss, heat gain and glare.

Access to natural light may be one of the most important attributes of a high performance school. Daylight is the highest quality light source for visual tasks, enhancing the color and appearance of objects. And studies clearly indicate that daylighting can enhance student performance. Views from windows also provide a connection with the natural world and contribute to eye health by allowing frequent changes in focal distance.

*Dena Boer Elementary School, Salida, CA*

*Skylights are used to distribute natural daylight to the classrooms, library, multipurpose room and offices of this 800-student, K-5 school near Modesto, California. Louvers installed in the skylight wells help control daylight levels and can be used to darken rooms when necessary. Classroom windows provide additional daylight and are protected by deep overhangs to control direct sunlight and glare.*

*All these "extras" were provided within the standard construction budget for the school, which was completed in 1997. The key was making daylighting a priority for the school and then shifting funds from elsewhere in the budget to pay for it.*

*The extra sunlight has proven very popular. "The skylights create an open, bright work environment. We just seem to have more room. Visitors say it sure is a pleasant place to come into," notes school principal Rick Bartkowski.*

Daylighting can also save a school money. Properly designed systems can substantially reduce the need for electric lighting, which can account for 35 to 50% of a school's electrical energy consumption. As an added benefit, waste heat from the lighting system is reduced, lowering demands on the school's cooling equipment. The savings can be as much as 10 to 20% of a school's cooling energy use. And daylight provides these savings during the day when demand for electric power is at its peak and electricity rates are at their highest.

### Energy Efficiency Checklist for Daylighting

**Design for diffuse, uniform daylight that penetrates deep into the space**

- ✓ *Use a daylighting analysis tool to help guide the design process.*
- ✓ *Design windows to allow daylight to penetrate as far as possible into a room. Consider using light shelves (solid horizontal elements placed above eye level, but below the top of the window) to reflect daylight deep into a room.*
- ✓ *Consider skylights (horizontal glass), roof monitors (vertical glass), light from two sides, and/or clerestory windows.*
- ✓ *Lay out the room to take advantage of daylight. Consider sloped ceilings. Consider light-colored ceiling surfaces to help reflect daylight within the room.*

**Avoid direct beam sunlight and glare**

- ✓ *Consider interior (shades, louvers or blinds) and exterior (overhangs, trees) strategies to control glare and filter daylight.*

**Integrate daylighting with the electric lighting system**

- ✓ *Provide controls that turn off lights when sufficient daylight exists. Consider dimming controls that continuously adjust light levels to respond to daylight conditions.*

## Building Enclosures

The building enclosure (walls, roofs, floors and windows) of a high performance school should enhance energy efficiency without compromising durability, maintainability, or acoustic, thermal or visual comfort. An energy-efficient building enclosure is one that integrates and optimizes insulation levels, glazing, shading, thermal mass, air leakage control, and light-colored exterior surfaces. An energy-efficient building enclosure will reduce a school's overall operating expenses and will also help the environment. Many of the techniques employed—high performance glazing, shading devices, light-colored surfaces—are easy for students to understand and can be used as instructional aids.

The key to optimizing the building enclosure is an integrated approach to design that considers how all the components of the building shell interact with each other and with the building's lighting and heating/ventilating/air-conditioning (HVAC) systems. Tools to analyze these interactions are readily available and can be used to create the optimal building enclosure based on total system performance. As part of an integrated approach, consider the actions described below.

*Oquirrh Hills Elementary School, Kearns, Utah*

***Well-insulated metal stud and brick veneer walls, a light-colored roof with R-30 rigid insulation, and windows with low-e glass all contribute to the superior energy performance of this elementary school near Salt Lake City.***

***The school, completed in 1996, replaced a previous facility that had been destroyed by fire. The new building saves roughly $22,000 per year in operating costs compared to its predecessor—a result of careful design combined with high performance systems and an energy efficient building enclosure.***

***Based on its experience with Oquirrh Hills, the Jordan School District has embraced high performance as a procurement goal and has gone on to build six more energy-efficient schools.***

***"High performance, energy smart school design means going 'beyond code'…cost effectively. That's just what the architects did at Oquirrh Hills," notes Duane Devey, Director of Energy and Utility Resources for Jordan School District.***

### Energy Efficiency Checklist for the Building Enclosure

**Specify high performance glazing**

- ✓ *Specify glazing that offers the best combination of insulating value, daylight transmittance and solar heat gain coefficient for the specific application.*

**Control heat gain and glare**

- ✓ *Consider exterior shading devices to reduce solar heat gain and minimize glare.*
- ✓ *Consider using light-colored materials for walls and roofs in order to reflect, rather than absorb, solar energy.*

**Consider high mass materials, like concrete or brick**

- ✓ *Use the building's thermal mass to store heat and temper heat transfer.*
- ✓ *Consider adding thermal mass to increase the storage capacity and energy efficiency of the building.*

**Control air leakage**

- ✓ *Consider air retarder systems (also referred to as "air infiltration barriers") as a means to improve energy performance and reduce potential water damage in walls and roofs*

### Efficient HVAC Systems

A school's HVAC system provides the heating, ventilating and air-conditioning necessary for the comfort and well-being of students, staff and visitors. To ensure peak operating efficiency, the HVAC system in a high performance school should: use high efficiency equipment; be "right sized" for the estimated demands of the facility; and include controls that boost system performance.

*Newport Mesa Elementary School, Costa Mesa, CA*

*After careful analysis of first costs versus performance benefits, high efficiency heat pumps—one for each classroom—were selected for this 400–700 student school south of Los Angeles. The equipment was designed and sized to work well with the natural ventilation systems built into each classroom. Controls for both systems are provided in each classroom so that teachers can maintain optimal conditions at all times.*

*The result is a school that provides a high performing HVAC system and empowers teachers to run it at peak efficiency.*

The HVAC system is one of the largest energy consumers in a school. Even modest improvements in system efficiency can represent relatively large savings to a school's operating budget. With the highly efficient systems available today—and the sophisticated analysis tools that can be used to select and size them—there's no reason why every school HVAC system can't be designed to the highest levels of performance.

The key to optimizing HVAC system performance is an integrated design approach that considers the building as a interactive whole rather than as an assembly of individual systems. For example, the benefits of an energy-efficient building enclosure may be wasted if the HVAC equipment is not sized to take advantage of it. Oversized systems, based on rule-of-thumb sizing calculations, will not only cost more, but will be too large to ever run at peak efficiency and will waste energy every time they turn on. An integrated approach, based on an accurate estimate of the impact of the high efficiency building enclosure, will allow the HVAC system to be sized for optimum performance. The resulting system will cost less to purchase, will use less energy, and will run more efficiently over time.

### Energy Efficiency Checklist for HVAC Systems

**Use high efficiency equipment**

- ✓ *Specify non-CFC (chlorofluorocarbon)—based refrigerants for systems using large chillers.*
- ✓ *Specify equipment that meets or exceeds the U.S. Department of Energy's "Energy Conservation Voluntary Performance Standards for New Buildings."*
- ✓ *Use ENERGY STAR-approved products.*
- ✓ *Consider recovery systems that pre-heat or pre-cool incoming ventilation air.*
- ✓ *Consider "economizer cycles" for small, packaged systems.*
- ✓ *In hot, dry climates, consider evaporative cooling. Investigate the potential for on-site cogeneration.*

**"Right-size" the system**

- ✓ *Consider standard HVAC sizing safety factors as upper limits.*
- ✓ *Apply any safety factors to a reasonable base condition for the building: not the hottest or coldest day of the year with maximum attendance; not the most temperate day of the year with the school half full.*
- ✓ *Select systems that operate well under part-load conditions.*

**Incorporate controls that boost system performance**

- ✓ *Consider integrated building management systems that control HVAC, lighting, outside air ventilation, water heating and building security.*
- ✓ *Consider individual HVAC controls for each classroom.*

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## Water Efficiency

Fresh water is an increasingly scarce resource in most areas of California. A high performance school should control and reduce water runoff from its site, consume fresh water as efficiently as possible, and recover and reuse gray water to the extent feasible.

Basic efficiency measures can reduce a school's water use by 30% or more. These reductions help the environment, locally and regionally. They also lower a school's operating expenses. While the cost savings may be modest now, since water is relatively inexpensive in most areas of the country, there is a strong potential that these savings will rise over time, especially in areas of California where water is scarce and becoming more expensive.

*Roy Lee Walker Elementary School*
*McKinney, Texas, Independent School District*

*Rain is "harvested" from the roof of this 608-student, K-5 school 30 miles north of Dallas, Texas and used to water the grounds and flush the toilets year round. The water is stored in six above-ground cisterns designed as integral components of the overall architecture of the facility.*

*The system shows how incredibly efficient rainwater collection can be, even in relatively dry locations. According to architect Gary Keep, just using the roof, "...enough water can be collected in a one-year period to flush toilets and water the grounds for about six years."*

The technologies and techniques used to conserve water—especially landscaping, water treatment and recycling strategies—can be used to help instruct students about ecology and the environment. Guidelines on the use of drought-resistant plants and efficient irrigation systems are provided in the Site Planning chapter. The HVAC guidelines discuss water consumption issues related to HVAC system choices. Opportunities to save water through water reclamation, gray water systems, and low-flow devices are discussed in the chapter on other (non HVAC) mechanical systems. The following checklist summarizes the key issues related to water efficiency.

### Water Efficiency Checklist

**Design landscaping to use water efficiently**

- ✓ *Reduce water use.*
- ✓ *Consider innovative wastewater treatment options.*
- ✓ *Specify hardy, native vegetation.*
- ✓ *Consider using an irrigation system for athletic fields only, not for plantings near buildings or in parking lots.*
- ✓ *Use high efficiency irrigation technology (e.g., drip irrigation in lieu of sprinklers).*
- ✓ *Use captured rain or recycled site water for irrigation.*
- ✓ *"Design in" cisterns for capturing rain water.*

**Set water use goals for the school**

- ✓ *Recommended goal: 20% less than the baseline calculated for the building (not including irrigation) after meeting the Energy Policy Act of 1992 fixture performance requirements.*

**Specify water-conserving fixtures and equipment**

- ✓ *Specify water-conserving plumbing fixtures that exceed Energy Policy Act of 1992 requirements.*
- ✓ *Specify high efficiency equipment (dishwashers, laundry, cooling towers).*
- ✓ *Consider single temperature fittings for student toilets/locker rooms.*
- ✓ *Consider automatic lavatory faucet shut-off controls.*
- ✓ *Consider low-flow showerheads with pause control.*

**Consider using recycled or rain water for HVAC/process make up water**

- ✓ *Decrease use of potable water for sewage conveyance by using gray and/or black water systems. Opportunities include toilet flushing, landscape irrigation, etc.*
- ✓ *Consider on-site wastewater treatment, including full or partial "solar aquatics" systems.*

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### Materials Efficiency

Materials efficiency in this manual refers specifically to two overarching goals: 1) waste reduction—including construction and demolition (C&D) source reduction, reuse and recycling; and 2) the use of building products that are manufactured in ways that conserve raw materials, energy and water, that are reused or salvaged, or that can be recycled or reused at the end of the building's service life. Addressing these goals provides significant environmental benefit. According to WorldWatch, buildings account for 40% of many processed materials used (such as stone, gravel and steel) and 25% of virgin wood harvested. These withdrawals can cause landscape destruction, toxic runoff from mines, deforestation, biodiversity losses, air pollution, water pollution, siltation and other problems.

*Ocean Park School, Santa Monica, CA*

*Certified sustainable yield lumber, formaldehyde-free particleboard and insulation, non-VOC sealants, and recycled plastic bathroom partitions were all incorporated into this 45,000 square foot, K-8 school in Santa Monica.*

*"It's not difficult to make our schools healthier and more environmentally responsible, but you have to start early in the process by 'designing in' high performance, non-toxic materials and products from the very beginning," says Betsey Dougherty, lead architect for the project.*

The checklist below summarizes key materials efficiency strategies. When considering recycled products or other materials-efficient products, be sure to consider their affect on acoustic, visual and indoor air quality. And be aware that using certain recycled products may conflict with goals for long-term materials efficiency, since a product's recycled composite may be difficult to recycle. Avoid products that unnecessarily complicate maintenance and operations procedures, and be sure that the custodial receives training in proper upkeep of the products. Using these strategies can help teach students about the role of waste reduction in protecting the environment.

#### Materials Efficiency Checklist

**Design to facilitate recycling**

- ✓ *"Design in" an area within the building dedicated to separating, collecting, storing and transporting materials for recycling including paper, glass, plastics and metals.*

**Reduce the amount of construction waste going to landfills**

- ✓ *Develop and implement a management plan for sorting and recycling construction waste.*
- ✓ *Consider a goal of recycling or salvaging 50% (by weight) of total construction, demolition or land clearing waste.*

**Specify salvaged or refurbished materials**

- ✓ *Evaluate the potential impact of salvaged materials on overall performance, including energy and water efficiency and operation and maintenance procedures.*

**Maximize recycled content of all new materials**

- ✓ *Use EPA-designated recycled content products to the maximum extent practicable.*
- ✓ *Use materials and assemblies with the highest available percentage of post-consumer or post-industrial recycled content.*
- ✓ *Consider a goal of having 25% of the school's building materials contain a weighted average of 20% post-consumer or 40% post-industrial recycled content.*

**Eliminate materials that may introduce indoor air pollutants**

- ✓ *Use materials or assemblies with the lowest level of volatile organic compounds (VOCs).*
- ✓ *Evaluate the potential impact of specified materials on the indoor air quality of the school.*

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## Commissioning

Building commissioning is the process of ensuring that systems in schools are designed, installed, tested and verified as being capable of operating according to the school's needs and the designer's intent. The term comes from shipbuilding where "commissioning a ship" means thoroughly testing it to ensure that it is seaworthy. For buildings, commissioning has a similar meaning, which is, testing the important building systems to ensure that they operate the way the designers expect and that they serve the needs of teachers, students and school districts.

High performance schools can only be achieved with some level of commissioning. Higher test scores, increased average daily attendance, reduced operational costs, teacher staff retention, and reduced liability may be compromised unless critical systems are commissioned to achieve proper performance. Because it anticipates problems, commissioning can avoid costly change orders, delays, and litigation. In addition to commissioning building systems, design professionals can commission high performance materials by making sure they are installed as specified, and that proper documentation exists so the design intent is not compromised in the event of cleaning, repair or replacement.

Studies show that many building systems will not operate as expected unless they are commissioned. One study of 60 newly constructed nonresidential buildings showed that more than half had controls problems, 40% had malfunctioning HVAC equipment, and one-third had sensors that did not operate properly. In many of the buildings, equipment called for on the plans and specifications was actually missing. One-fourth of the buildings had energy management control systems (EMCS), economizers or variable-speed drives that did not run properly.[2]

### Systems that Require Commissioning

Commissioning can reduce these problems by systematically assuring that the critical systems are properly installed, calibrated and working. Systems for which commissioning is essential include lighting sweep systems, photocell daylighting controls, energy management systems, variable speed motor drives, building pressurization control, floating head pressure in refrigeration equipment, anti-condensate heaters in refrigeration systems, and capacity controls in central heating and cooling plants. A more comprehensive list of systems that might require commissioning include:

- HVAC plant
- Air and water delivery system
- Energy management system
- Electrical and lighting system
- Fire/life safety system
- Data networks/communications
- Security system
- Kitchen equipment and fume hoods
- Building envelope
- Renewable energy system
- Science lab gas delivery system
- Emergency power supply
- Plumbing
- Irrigation system

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[2] Piette, Mary Ann. 1994. Quantifying savings from commissioning. Preliminary results from the Northwest. Lawrence Berkeley National Laboratory.

### The Commissioning Agent

The commissioning agent is responsible for coordinating and carrying out the commissioning process. For complex projects, the commissioning agent should be brought on as part of the design phase. However, for most schools, commissioning may not be needed until construction start-up, and knowledgeable in-house personnel may fill the role of the commissioning agent. Commissioning should continue well into start-up, and be integrated into the operations and maintenance plan.

The responsibilities of the commissioning agent include:

- Assisting with a clear statement of the design intent for each building system.
- Writing the commissioning specifications and incorporating them in the appropriate divisions of the construction specifications.
- Carrying out pre-functional and functional testing of all equipment and systems to be commissioned, using procedures designed in advance.
- Reviewing operation and maintenance (O&M) documents to be provided by the contractor.
- Developing O&M training curricula and materials to ensure they meet needs of O&M staff.
- Writing a final report including all commissioning documentation and recommendations for the owner.

### *Cost of Commissioning*

For California schools, the cost of commissioning ranges between $0.10 and $0.30 per square foot of building area. Studies show that commissioning can be very cost effective, with simple paybacks ranging between four months and 20 months.[3]

### *Commissioning References*

American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE). 1996. *The HVAC Commissioning Process, ASHRAE Guideline 1-1996*. Available on-line at http://www.ashrae.org.

*Commissioning Specifications, C-2000 Program*, Canada, 1995.

NEBB. 1993. *Procedural Standards for Building Systems Commissioning*.

U.S. Department of Energy (DOE). 1998. *Model Commissioning Plan and Guide Specifications*. NTIS #DE97004564. Available on-line at http://www.peci.org.

U.S. Green Building Council. *LEED 2.0 Reference Guide* (for commercial buildings). Available at http://www.usgbc.org.

## CHPS Eligibility Criteria

Environmental performance criteria for California High Performance Schools are set forth in Volume III of this manual. To achieve a high level of environmental performance, performance criteria and goals need to be clearly stated in both the educational specification and the architectural program. Having specific criteria for a high performance school makes it easier for school districts to describe what they want and for architects to meet these goals. Volume III provides school districts and designers with specific yet flexible criteria for building high performance schools.

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[3] Gregerson, Joan. 1997. Cost effectiveness of commissioning 44 existing buildings.

## Material Selection and Research

In a high performance school, materials are selected for several characteristics beyond the traditional issues of performance, price, availability and aesthetics. Designers should look for environmentally preferable materials that are:

- **Durable.** Offers (proven) longer service life compared to other options in a given product category.
- **"Healthy."** Does not introduce toxics or polluting emissions into the building.
- **Made with recycled content.** Includes materials that have been recovered or otherwise diverted from the solid waste stream, either during the manufacturing process (pre-consumer), or after consumer use (post consumer).
- **Salvaged or reused.** Includes materials that are refurbished and used for similar purpose; not processed or remanufactured for another use.
- **Recyclable.** Can be collected, separated, or otherwise recovered from the solid waste stream for reuse, or in the manufacture or assembly of another package or product.
- **Sustainably produced.** Extracted, harvested or manufactured in an environmentally friendly manner (includes certified wood products).
- **Environmentally benign.** Includes or introduces no or low known pollutants to the natural ecosystem ( includes non ozone-depleting or toxic materials).
- **Low in embodied energy.** Does not require significant amounts of energy to produce or transport the material (includes locally manufactured or extracted options in a given product category).
- **Produced from rapidly renewable material.** Includes material that is grown or cultivated and can be replaced in a relatively short amount of time (defined by the type of material).
- **Made with industrial byproducts**. Includes material that is created as a result of an industrial process (flyash, for example).
- **Marketed in an environmentally responsible manner.** Includes products available with minimal packaging.

For the high performance label to be meaningful, it's important for designers to ensure that a significant number of materials used for the project meet one or more of the above attributes. This will require research and documentation. There are many sources of information to help with in this process.

### Product Suppliers

Some building materials suppliers are making significant efforts to incorporate sustainable goals in their processes and operations and in their products. Companies serious about this commitment will provide detailed information about their product's performance. When investigating products, it is always recommended that the design team consult with the manufacturer's technical rather than sales staff.

### Material Safety Data Sheets

Material Safety Data Sheets (MSDS), which must be prepared by product manufacturers, can provide some information and in particular can help "red flag" problem ingredients that may be toxic or emit significant volatile organic compounds (VOCs). For example, the Health Hazard Rating (0 is low, 5 is high) found on an MSDS provides some indication of whether a product is appropriate for indoor school environments. MSDS's are often incomplete, however. Generally they do not include information about environmental attributes other than toxicity of regulated ingredients. MSDS's are primarily useful for eliminating building materials that may cause serious environmental problems.

## Product Certification

Product certification programs can help identify environmentally preferable products. Many product suppliers have increased the credibility of their environmental claims by obtaining industry or independent certifications of their products' environmental attributes. Independent programs provide the most objective documentation and include:

- *Green Seal.* Green Seal standards are based on environmental protection. They focus on reduced air and water pollution, reduced consumption of energy and other resources, protection of wildlife and habitats, reduced packaging, quality, and performance. Tel: (202) 588-8400. Web site: http:///www.greenseal.org.
- *Scientific Certification Systems (SCS).* SCS is a nonprofit organization that assesses products based on a life-cycle or "cradle to grave" evaluation. Their Environmental Report Card gives detailed information about the environmental burdens associated with the production, use and disposal of the product. Tel: 800-ECO-FACTS. Web site: http://www.scs1.com.
- *Energy Star.* A program of the federal government, manufacturers are allowed to use the Energy Star label only if the product meets certain energy efficiency levels set by either the U.S. Environmental Protection Agency or U.S. Department of Energy. Tel: (888) STAR-YES. Web site: http://energystar.gov.
- *Forest Stewardship Council.* A product bearing the Forest Stewardship Council (FSC) trademark is made with wood certified to have come from a forest that is well managed according to strict environmental, social and economic standards. FSC is an international nonprofit association working in partnership with industry and other groups to improve forest management worldwide. Tel: (802) 244-6257. Web site: http://www.fscoax.org. Also see Smart Wood, a U.S.-based program of the Rainforest Alliance, accredited by the FSC for the certification of forest management. Tel: (802) 434-5491.Web site: http://www.smartwood.org.

## Environmentally Preferable Product Directories

There are several good directories that identify environmentally preferable product options. Some focus on a product category (for example, recycled content products), while others cross categories.

- Architects/Designers/Planners for Social Responsibility (ADPSR), Northern California chapter. *Architectural Resource Guide.* Organized by CSI, this guide lists sustainable, less polluting, local, and recycled building products as well as related information and a recommended reading list. Available as hard copy or CD. Web site: http://www.adpsr-norcal.org.
- *California Multiple Awards Schedule (CMAS).* Schools can now directly purchase products listed on CMAS, part of the state's procurement system. This allows direct purchases without going through the bidding process, saving time and offering economy of scale. Products are less expensive than if purchased through other means, but schools are encouraged to negotiate prices further. Schools may issue a purchase order directly to the supplier, while sending a copy of it to this address: CMAS, 1500 5th St. Suite 116, Sacramento, CA 95814. For assistance call the CMAS information line at (916) 324-8045. Web site: http://www.pd.dgs.ca.gov (select CMAS).
- U.S. EPA's *Preliminary Guidelines for Recycled Content.* Web site: http://www.epa/gov/epaoswer/non-hw/procure/products.htm.
- *Guide to Resource Efficient Building Elements (GREBE).* 1998. Edited by T. Mumma. Contact: Center for Resourceful Building Technology, Box 100, Missoula MT 59806. Tel: (406) 549-7678.

Web site: http://www.montana.com/crbt. Resource book on resource-efficient building systems. Updated regularly.

- *GreenSpec: The Environmental Building News Product Directory and Guidelines Specifications.* 1999. Published by E Build, Inc., Brattleboro, VT. Tel: (802) 257-7300. Web site: http://www.buildinggreen.com. *GreenSpec* is organized in standard CSI divisions.
- *REDI Guide (Resources for Environmental Design Index).* Available as web database, diskette, or printed handbook; a good resource for energy-efficient products. Contact: Iris Communications, Eugene, OR. Tel: (800) 346-0104. Web site: http://www.data.oikos.com/products \.
- California Integrated Waste Management Board's web site, http://www.ciwmb.ca.gov, provides a "Recommended Recycled Content Product Procurement List." The database is searchable by CSI section number and provides links to manufacturers.
- *The Harris Directory.* Edited by B.J. Harris. Contact: The Harris Directory,1583 Pacheco St. #125, Santa Fe, NM 87505. Tel: (888) 844-0337. Web site: http://www.harrisdirectory.com. A database (for Mac or Windows) of recycled content products by category.
- U.S. EPA's *Comprehensive Procurement Guidelines (CPG).* The CPG program promotes the use of materials recovered from solid waste. Web site: http://www.epa.gov/epaoswer/non-hw/procure/index.htm. The Products page, http://www.epa.gov/epaoswer/non-hw/procure/products.htm, provides an online list of construction, landscaping and other categories of products. The web site briefly describes each of the listed products. You also can view EPA's recommended recycled content ranges and a list of manufacturers, vendors and suppliers for each item. Also see the *Database for Environmentally Preferred Products*: http://notes.erg.com (this is an EPA contractor's web site).

## Environmentally Preferable Product Evaluation Tools

The following resources provide methodologies or suggestions for evaluating products:

- BEES (Building for Environmental and Economic Sustainability) software helps analyze the environmental and economic performance of some building products. The software is downloadable at http://www.bfrl.nist.gov/oae/software/bees.html.
- *Environmental Resource Guide.* 1996. Edited by Joseph A. Demkin. Offers a methodology for preparing life-cycle assessments of building materials, materials comparisons, and case study information about how high performance buildings have worked in practice. Available through Iris Communications online at http://shop.oikos.com/catalog. Tel: (800) 346-0104.
- *Environmental Building News (EBN).* Brattleboro, VT. Tel: (802) 257-7300. Web site: http://www.buildinggreen.com. The leading green building professional journal. Offers excellent articles, product reviews, book reviews and resources. For online EBN product reviews available. Two pertinent articles are: "What Makes a Product Green?" (Vol. 9, No. 1: January 2000), which offers a simple methodology for evaluating a product; and "Material Selection Tools, Resources and Techniques for Choosing Green," (Vol. 6, No. 1: January 1997), which offers a survey of analytical tools and references for evaluating environmentally preferable materials.
- *Proceedings from the LAUSD Workshop on Sustainable Schools.* February 16, 2000. See the Breakout Session section on "Green" Materials and Systems, and other related sections. Available online at http://www.eley.com/lausd.

## General Purpose Design and Evaluation Tools

Appropriate design tools are discussed in the overview of each technical chapter and within each guideline. Some general design and analysis tools are addressed here because they are common to many of the technical chapters that follow.

### General Design Tools

Green Building Advisor™ (GBA) is a CD-ROM based software tool that can be used as a "first cut" to help designers identify building design strategies that can be incorporated into specific projects. Based on inputs provided by the user, GBA generates a list of prioritized strategies organized by categories. The software provides information on relative cost as well as case studies where the strategy has been implemented. Registered users get a user's manual and free technical support. For more information, call (802) 257-7300 or visit http://www.buildinggreen.com.

### Energy Analysis Tools

These are computer programs designed to predict the annual energy consumed by a building. They can be used to evaluate the energy impacts of various design alternatives and, in particular, to compare specific low-energy strategies (for example, higher insulation levels, better glazing, increased thermal mass) in terms of their impacts on overall building performance. Combined with accurate cost estimates, they can help create a high performance school that is optimized in terms of its overall energy performance, which can save money on initial construction costs as well as on long-term operating expenses.

For example, a school that combines daylighting strategies and highly efficient electric lighting in its classrooms will require less electricity to illuminate those classrooms, providing a long-term operating savings. In addition, the rooms, because they take advantage of daylight and use high efficiency lamps, may need fewer light fixtures overall to achieve a high quality visual environment, providing an upfront savings on initial costs. Finally, highly efficient lighting—and, potentially, fewer light fixtures—will result in less waste heat in each classroom. This, in turn, will allow the cooling system for the classrooms to be smaller, generating additional upfront savings.

A wide number of energy analysis tools are currently available, some appropriate for the early stages of a project, some for the later phases. A sampling of these tools is provided below. Energy performance analyses using one or a combination of these tools should be conducted during each of the following design phases: programming, schematic design, design development, construction documents, and bidding and negotiation.

### Architectural Design Tools

These are used primarily during a project's programming, schematic design, and design development phases.

- *ENERGY-10.* Contact: Sustainable Buildings Industry Council. Web site: http://www.sbicouncil.org.
- *Building Design Advisor.* Contact: Lawrence Berkeley National Laboratory. Web site: http://gundog.lbl.gov.

- *Energy Scheming.* Contact: Iris Communications. Web site: http://www.oikos.com/esb/37/scheming.html.
- *VisualDOE.* Contact: Eley Associates. Web site: www.greendesigntools.com.

### Load Calculation and HVAC Sizing

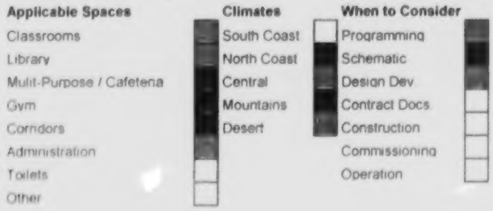
These are used primarily during a project's design development and construction documents phases.

- *EnergyPlus.* This computer program, which is being developed by the U.S. Department of Energy, is considered to be the successor to both DOE-2 and BLAST. It combines features from both programs and includes modules for the thermal analysis of windows, radiant transfer within spaces and other features. Contact: Lawrence Berkeley National Laboratory. Web site: http://gundog.lbl.gov.
- *DOE-2.* This widely used program for analyzing the energy efficiency of buildings uses an hourly weather file and simulates energy performance during a typical year. Contact: Lawrence Berkeley National Laboratory. Web site: http://gundog.lbl.gov. There are several Windows user interfaces that make it easier to use DOE-2, including VisualDOE, PowerDOE, and EnergyPro.
- *HAP.* Contact: Carrier Corp. Web site: http://www.carrier.com.
- *TRACE.* Contact: Trane Corp. Web site: http://www.trane.com.
- *BLAST.* Contact: University of Illinois. Web site: http://www.bso.uiuc.edu.

## Anatomy of a Guideline

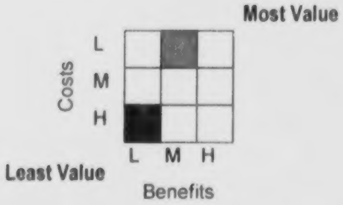
Each of guidelines in Volume II follows the format explained below. Information relevant to multiple guidelines is typically discussed in the Overview for that chapter.

- **Recommendation:** a short phrase describing what to do.
- **Description:** the technology or design strategy in more detail.
- **Applicability chart:** associates the guideline to particular spaces, climate zones, and design process steps. An example is shown below. The black areas indicate strong applicability and the gray areas indicate limited applicability. Unshaded areas indicate that the guideline is not applicable.



- **Applicable Codes:** codes or regulations that apply. Note local ordinances that might apply in some jurisdictions, but not all.
- **Integrated Design Implications:** implications that the design strategy or technology might have on other building systems, e.g. if cooling load is significantly reduced by high performance fenestration, the HVAC system might be made smaller and natural ventilation might become more viable. Discusses the phase of design when the strategy or technology might best be implemented.
- **Costs:** information on construction costs, when possible. Provides data on a \$/ft² or \$/classroom basis. Identifies and quantifies O&M costs when applicable and possible. Describes environmental costs or externalities that cannot be given a dollar value.

- **Benefits:** the benefits that can be expected from implementation of the measure. Includes energy savings benefits, improvements in indoor environmental quality, productivity benefits, and possible impact on average daily attendance.
- **Cost Effectiveness:** the benefits and costs of the strategy/technology on both a system basis and an overall project basis. The chart below shows construction costs on the vertical scale varying from low to medium to high. Benefits are on the horizontal scale, again varying from low to medium to high. A black mark shows the overall project impact and a gray mark for the system impact. In the diagram below, the system benefits are medium and the system costs are high, while the overall costs and benefits are low.



For ranking the *system* benefits and costs: Low represents an increase in costs or benefits of 0-20% over the basecase system, medium is a cost increase of 20-50% over the basecase system and high is an increase in costs or benefits of more than 50% over the basecase system.

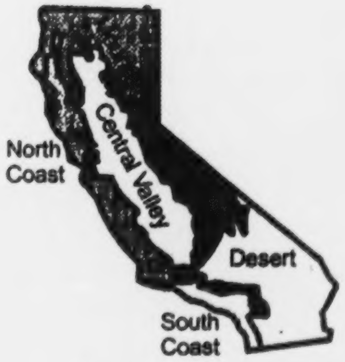
For ranking the *overall* benefits and costs: Low represents an increase in costs or benefits of 0-2% over the basecase system, medium is a cost increase of 2-8% over the basecase system and high is an increase in costs or benefits of more than 8% over the basecase system.

The cost scale refers only to the initial construction cost, which is a big issue with schools and the architects that design them. On an overall basis, low means that the incremental construction cost is small or even negligible and that the district should be able to afford the strategy/technology with the normal school construction budget. Medium cost means that the strategy/technology will cost a little more and the school construction budget will need to be supplemented or that savings will need to be realized from other systems, e.g. HVAC downsizing.

- **Design Tools:** any design tools, including software that can be used to optimize the design, quantify the benefits or estimate construction costs. In some cases, a technique might be described on how a general purpose tool such as DOE-2 might be used to evaluate and analyze the design.
- **Design Details:** more thorough details on the design. These might include rules of thumb, specific recommendations, sample specifications, or schematic diagrams.
- **Operation and Maintenance Issues:** O&M requirements, e.g. what needs to be done with the strategy/technology in order for it to continue to perform optimally.
- **Commissioning:** the need for calibration, functional tests, static tests, commissioning plan requirements, statement of design intent, post occupancy tests and other issues and requirements related to commissioning of the strategy/technology.
- **Example(s):** schools that have incorporated the strategy/technology.
- **References / Additional Information:** references where the reader can get additional information about the strategy/technology.

## Climates

The guidelines are developed for five California climate regions. Many of the recommendations depend on the climate where the school is constructed. When this is the case, the recommendations will be keyed to one of the five California regions.


North Coast
Central Valley
Desert
South Coast

*California Climate Regions*

# GENERAL CONDITIONS

This chapter provides guidelines for preparing the general conditions portion of the construction specification. These are mostly requirements for the general contractor and include:

Developing and implementing a sustainable job-site operations plan (Guideline GC1)

Managing construction and demolition (C&D) waste (Guideline GC2)

Taking steps to protect indoor air quality during construction (Guideline GC3)

Protecting the site during construction (Guideline GC4)

Requiring contractors to perform commissioning activities (Guideline GC5)

## Overview

The primary intent of the guidelines in this chapter is to ensure the methods used to build the school and operate the construction site are environmentally sound. These guidelines recognize that it is not only important to end up with a high performing school, but that the means to get there should be consistent with that end.

During construction, there are literally hundreds of opportunities to work toward fulfilling the environmental goals of a high performance school or, alternatively, to compromise them. To ensure the construction process is consistent with these goals, contractors should be made aware of them upfront, as part of the bidding process. Ideally, the selected contractor should have experience with some of the practices recommended in this Best Practices Manual. Minimally, they should be aware of, and responsive to, the goals set for the project. The clearer the expectation that contractors will play an important role in achieving these goals, the more likely the construction process will go smoothly in this regard.

Guideline GC1 requires that contractors develop and follow a sustainable job-site management plan. This plan should include protocols for waste reduction (GC2), indoor air quality (GC3) and site protection (GC4). Contractors also play a key role in the success of a commissioning plan, in that they can provide specific information needed for the commissioning process, and are likely to be involved when corrections are indicated. The contractor's commissioning responsibilities are spelled out in Guideline GC5.

### Using Environmentally Preferable Methods During Construction

During construction, general and trade contractors have a significant role to play in making efficient use of materials, preventing future indoor air quality problems, and protecting the site from degradation. Several of the guidelines will help designers direct contractors in this capacity.

In practice, requiring the contractor to produce and implement a job-site operations plan has proven to be *the* most effective way to ensure that environmental goals will be given equal treatment along with other project goals. In addition, including a requirement to produce and implement a job-site operations plan in bid documents, and in particular in the contract language of specifications, levels the bidding playing field.

In general, sustainable job-site operational costs are minimal, and cost benefits can be significant. Planning helps minimize expense and liabilities, including expensive delays, stoppages, and callbacks due to mistakes made during construction. Savings due to job-site waste reduction practices are well-documented. Contractors familiar with sustainable job-site operations will know the benefits and understand that it is not complicated. Contractors unfamiliar with them, however, will assume it costs more and bid accordingly. Bid packages should contain references to existing resources to help contractors familiarize themselves with such plans and provide tools to estimate costs and benefits more accurately.

A sustainable job-site operation will use a combination of contract language, signage, discussions at weekly job-site meetings, and incentives/rewards to educate and motivate field personnel and make sure everyone is acting in concert. Brief presentations, signage that both informs and motivates by reporting progress toward environmental goals, and contractor's field guides can be helpful communication aids. On most construction sites, signage and other printed instructions will need to be understandable by individuals for whom English is a second language.

In addition, contractors with the most success identify an individual (often the safety officer) who can enforce the sustainable job-site operations plan on a day-to-day basis. With many recommended job-site practices, it would be difficult to determine whether they are actually occurring unless there is regular in-the-field monitoring. Ideally, the same individual monitoring compliance would take an active role in training and other on-site educational efforts.

### Achieving the Design Intent of a High Performance School

Perhaps the most important contribution the contractor can play in achieving high performance goals for the school is in participating in the commissioning (Cx) process. The entire point of this process is to demonstrate that the installed components of building systems meet the original design intent. (See other sections on commissioning in Volume I and Volume II for more detailed discussions of the process.) Contractors can play a key role in effective commissioning by providing timely documentation, understanding the importance of thorough testing and tuning, paying attention to detail when correcting problems, and in general being responsive to the commissioning agent's recommendations and requests.

Installation schedules of a high performance school may be different from a conventional school. For example, the California Department of Health Services' "Reducing Occupant Exposure to Volatile Organic Compounds (VOCs) from Office Building Construction Materials Non-Binding Guidelines" recommend that "porous materials, such as carpets and fabric-covered office dividers…be installed last." This practice prevents the porous materials from acting as a "sink" for VOCs being emitted by wet products (paints and other finishes, for example). Proper sequencing can be spelled out in execution articles of pertinent specification sections, but may also be called out in general conditions. In addition ventilation requirements during and after installation and flush-out practices will need to be specified in appropriate sections.

In addition, product substitutions (especially those made in the field due to last minute availability problems) can be an opportunity to lose sight of original design intent. When there are substitutions in the field, submittals must show that these substitutions possess the environmentally preferable characteristics of the original product or material specified. A sustainable job-site operations plan should specify a method of providing documentation for products substituted, so that in the event of replacement or repair, the information is available to custodial staff. In addition, when dealing with non-conventional or innovative materials, it can be helpful to note information in a field log about how a product behaves during installation and pre-occupancy maintenance (such as during cleanup) as well as other "lessons learned."

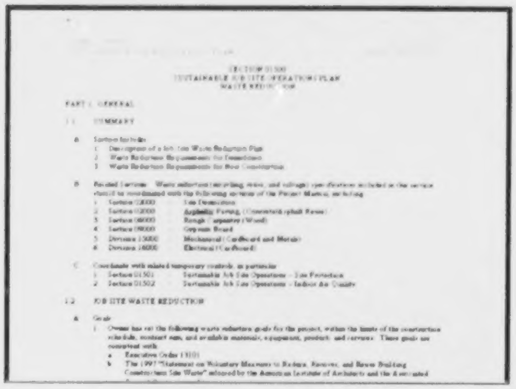
# Guideline GC1: Sustainable Job-site Management

### Recommendation

Require a job-site operations plan that includes protocols for Job Site Waste Reduction (see Guideline GC2), Indoor Air Quality (see Guideline GC3), and Site Protection (see Guideline GC4).

### Description

A sustainable job-site operations plan will describe goals, construction practices to be used to achieve those goals, methods to train or otherwise communicate these goals to field personnel, and methods to track and assess progress towards those goals. For each component of the plan (waste reduction, indoor air quality, and site protection) these elements will be specified. In addition, the plan will specify the method of documenting compliance with these goals, including in the case of product substitutions.



*Sample Sustainable Job Site Operations Plan*

| Applicable Spaces | | Climates | | When to Consider | |
|---|---|---|---|---|---|
| Classrooms | ■ | South Coast | ■ | Programming | □ |
| Library | ■ | North Coast | ■ | Schematic | □ |
| Multi-Purpose / Cafeteria | ■ | Central | ■ | Design Dev | ▨ |
| Gym | ■ | Mountains | ■ | Contract Docs | ▨ |
| Corridors | ■ | Desert | ■ | Construction | ■ |
| Administration | ■ | | | Commissioning | □ |
| Toilets | ■ | | | Operation | □ |
| Other | ■ | | | | |

### Applicability

Job-site management is applicable to all spaces in schools and to all climates. While it is carried out in the construction phase, the contract documents must clearly specify the expectations of the general contractor.

### Applicable Codes

There are many jurisdictions in California (at the county and city level) that have developed or are developing ordinances that require job-site waste management planning. (See GC2 for more information). In addition, local school districts are beginning to develop IAQ policies that incorporate some construction operational requirements. (See GC3 for more information.) The U.S. Green Building Council's LEED Green Building Rating System (Commercial, Version 2) includes a provision for an IAQ construction plan as well. All jurisdictions include some requirements related to water quality protection, in particular stormwater management during construction. More communities are adopting "green building ordinances" that capture some elements of sustainable job-site operations.

### Integrated Design Implications

The primary reason for a sustainable job-site operations plan is to protect the integrity of design goals to reduce waste, improve air quality, and protect the site and surrounding waterways from degradation. In addition, it will highlight the contractor's responsibilities to document the environmental attributes of materials (such as recycled content, low emitting, or low toxicity) in the case of in-field substitutions.

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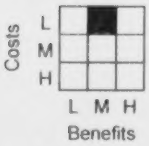
## Costs

Costs for implementing the plan will include labor for overseeing and documenting compliance, and should not be significant.



## Benefits

Having a plan in place helps minimize costs and liabilities, including delays, stoppages, and residual problems in the completed school building. Planning is always more cost-effective than cleaning up after a mistake.

## Design Tools

Not applicable.

## Design Details

The more clearly a plan allocates responsibilities and expectations, the less likely the project will generate unpleasant surprises during and post construction. Ideally, the plan should specify a time requirement by which a plan must be submitted, such as within 14 days of Notice of Award and prior to applicable construction activities. In addition, it can include sample forms, references, or other resources for the contractor to help facilitate development of an effective plan. The requirement for a sustainable job-site operations plan would appear in the "Temporary Controls" section(s) of specifications. Sample specifications for the three plan components recommended in this guideline—job-site waste reduction, IAQ, and site protection—can be found in the electronic Appendix A[4].

## Operation and Maintenance Issues

In particular, the plan should specify a method of providing documentation for products substituted in the field, so that in the event of replacement or repair, the information is available to custodial staff. In addition, when dealing with non-conventional or innovative materials, information about how a product behaves during installation and pre-occupancy maintenance (such as during cleanup), as well as other "lessons learned" noted in a field log can be helpful.

## Commissioning

Not applicable.

## Example(s)

NA

## References/Additional Information

Please see references listed for individual components of the plan. Also see electronic Appendix A for sample specifications language.

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[4] The electronic appendices are located on-line at http://www.eley.com/chps/manual or on the CD-ROM version the Manual.

# Guideline GC2: Construction and Demolition (C&D) Waste Management

## Recommendation

Require waste reduction planning and job-site practices. These guidelines recommend that a sustainable job-site operations plan (see Guideline GC1) be developed that incorporates a job-site waste reduction component. An alternative is to develop a stand-alone C&D Waste Management Plan.

Conducting a Construction Site Waste Audit. Photo courtesy of O'Brien & Company

| Applicable Spaces | | Climates | | When to Consider | |
|---|---|---|---|---|---|
| Classrooms | ■ | South Coast | ■ | Programming | ☐ |
| Library | ■ | North Coast | ■ | Schematic | ☐ |
| Multi-Purpose / Cafeteria | ■ | Central | ■ | Design Dev. | ▨ |
| Gym | ■ | Mountains | ■ | Contract Docs | ▨ |
| Corridors | ■ | Desert | ■ | Construction | ■ |
| Administration | ■ | | | Commissioning | ☐ |
| Toilets | ■ | | | Operation | ☐ |
| Other | ■ | | | | |

## Description

Effective job-site waste management will reduce the amount of construction and demolition (C&D) waste generated and divert materials generated through C&D processes from disposal through reuse (salvage) and recycling. This effort can be combined with a concerted use of salvaged or recycled-content building materials throughout the building project; specific materials would be called out in appropriate sections of project specifications.

C&D waste management will include the development of a waste reduction plan; identify personnel responsible for implementing and monitoring the plan, and outline consequences of non-compliance. Waste management should reflect the prioritized hierarchy of "Reduce, Reuse, and Recycle" with recycling efforts occurring in concert with "source reduction" and applying only to materials that *cannot be reused.*

## Applicability

Construction waste management is applicable in all climates and in all types of school spaces. While carrying it out takes place during the construction phase, the contract documents must clearly layout the responsibilities of the general contractor.

## Applicable Codes

Because local jurisdictions in the State could face fines for not meeting the State goal of diverting 50% of waste from landfills by December 31, 2000, many jurisdictions in California (at the county and city level) have developed or are developing ordinances related to C&D waste management. In some cases these ordinances apply only to municipally owned projects, but not always. Some of the ordinances exempt C&D projects below a specified dollar value or size, but not always.

These ordinances generally require a C&D waste management plan and documentation of implementation for permitting, and often provide a sample form for this purpose. In some cases the ordinances require a minimum level of C&D materials diversion from landfill or at the very least, a "good faith effort." In addition, at least two ordinances require deposits held until proof of compliance with waste reduction requirements has been provided.

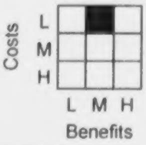
Whether you develop a stand-alone C&D waste management plan or a job-site waste reduction plan as part of an overall sustainable job-site operations plan, it will be important to be familiar with relevant ordinances to ensure your project specifications are in compliance. For a sample of C&D waste related ordinances, see http://www.ciwmb.ca.gov/ConDemo/SampleDocs.

## Integrated Design Implications

Some waste reduction can be designed into the building project, such as standardized dimensioning, the use of modular or panelized building units, and layout of openings (see the chapter on Building Enclosure). Specifying the use of mechanical fasteners (screws, Velcro) rather than chemical adhesives and solvents will allow components to be easily disassembled and reused.

It will be important that intent of these design details be made clear to avoid in-the-field decisions that waste materials. In addition, a requirement is needed to document recycled content or other resource-efficient attributes for materials substituted in the field due to scheduling needs or availability. Contractors are excellent problem solvers, and should be encouraged to find cost-effective substitutes that they know will meet or exceed the environmental goals.

## Costs



Costs can include labor for overseeing and implementing the C&D waste reduction (or waste management) plan, rental for additional bins or other containers used for recycling or salvage, and transportation. Research indicates labor costs decrease significantly as contractors become more familiar with job-site waste reduction techniques. Some contractors keep costs down by utilizing temporary lay down areas contained by plywood barriers rather than renting bins or containers to hold recyclables. Alternatively, planning ahead and ordering bins only when they are needed can keep down costs. This works because C&D materials are typically generated at predictable phases of the project.

## Benefits

In general, C&D waste reduction should also reduce overall construction costs, especially as this becomes a part of doing business (present in every job), and the C&D recycling/reuse infrastructure matures. If revenues from waste reduction, reuse/salvage, and recycling are allocated to the contractor, this puts the responsibility (and the incentive) for waste reduction clearly in the contractor's domain. Most contractors report that having a good waste reduction program in place results in a cleaner, safer site. This means less lost time and delay.

Environmentally, less waste means better use of limited raw materials and of the energy required to produce, transport, and dispose of building products used in the project. Also, recycling provides "stock" for new materials to be manufactured.

## Cost Effectiveness

Waste disposal/management is generally budgeted as a very small portion of overall job costs. However, cost of purchasing materials to replace materials that are wasted is rarely taken into account. Although the cost-benefits of a safer site due to effective waste reduction planning has not been adequately researched, anecdotal reports from contractors indicate that there are some. There is a tendency to assume that effective waste reduction takes more time and "costs more" as a result, but this is not borne out in case studies, if labor crews are adequately trained and a good plan is in place.

## Design Tools

See the electronic Appendix A for sample specification language. Also see sample specifications included in *Green Spec: The Environmental Building News Product Directory and Guideline Specifications*.

## Design Details

Scheduling should permit salvaging and deconstruction activities as may be appropriate.

Waste reduction goals (as with all other sustainable building goals) should be outlined in the Instructions to Bidders as part of the Project Summary. California Integrated Waste Management Board recommends a goal of 75% diversion of C&D materials by weight. In addition, waste reduction specifications should be included in the Temporary Controls sections of General Conditions.

As part of identifying those materials that should be targeted for recycling or reuse in a particular project, contact the local waste authority for information about building materials that can be cost-effectively recycled or salvaged in the project area. These materials should be called out for recycling in the general conditions specifications section pertaining to waste reduction and in pertinent sections. For example, gypsum drywall, which can typically be recycled cost-effectively, would be listed in the general conditions specification along with other materials that are to be recycled. A requirement to recycle gypsum drywall would also be included in the Division 9 section for gypsum drywall assembly.

Waste reduction specifications should reflect local jurisdictional requirements, but should be organized using typical CSI convention. The specifications should: describe what is included in the job-site waste reduction plan, outline submittal and documentation requirements, indicate ownership of revenues resulting from waste reduction efforts, and include performance goals, such as minimum levels of waste reduction. The specifications should also outline remedies in the event those levels cannot be met.

If the contractor is required by ordinance or specification to be responsible for achieving waste reduction, it is not necessary to detail methods by which the contractor can achieve it. However, it is informative to contractors to include a list of proven waste reduction strategies, such as:

- A waste reduction provision in supply agreements specifying a preference for reduced, U-turn, and/or recyclable packaging.
- Detailed take-offs that identify location and use in structure to reduce risk of unplanned and potentially wasteful cuts.
- Proper storage of materials to avoid wetting or other damage to materials as well as outdating. Materials that become wet or damp due to improper storage shall be replaced at contractor's expense.
- Safety meetings, signage, and subcontractor agreements that communicate the goals of the waste reduction plan
- On-site instruction regarding appropriate separation, handling, recycling, salvage, reuse, and return methods to be used to achieve waste reduction goals.
- Protection of materials to be recycled from contamination.

Contractors familiar with job-site recycling will know its benefits and understand that it is not complicated. Contractors unfamiliar with recycling, however, will assume it costs more and bid accordingly. To facilitate job-site recycling, provide references that explain the waste management planning process clearly and provide tools to estimate costs and benefits accurately. Several are listed below.

### Operation and Maintenance Issues

Contractors should be required to provide information on product substitutions sufficient to enable O&M staff to properly maintain and repair recycled-content or otherwise resource-efficient materials in place.

### Commissioning

Not Applicable

### Example(s)

Fruitvale School, Oakland Unified School District. Project in initial design. Includes demolition. For more information contact Dana Papke, DPapke@CIWMB.ca.gov.

Ross Middle School, Ross School District. Completed in 1999. For more information contact Dana Papke, DPapke@CIWMB.ca.gov.

### References/Additional Information

California Integrated Waste Management Board (CIWMB) web site. In particular, see "Job Site Source Separation," a fact sheet located at http://www.ciwmb.ca.gov/ConDemo/factsheets/JobSite.htm.

U.S. Green Building Council's *Reference Manual* for LEED Green Building Rating System (Commercial, Version 2) at http://www.usgbc.org.

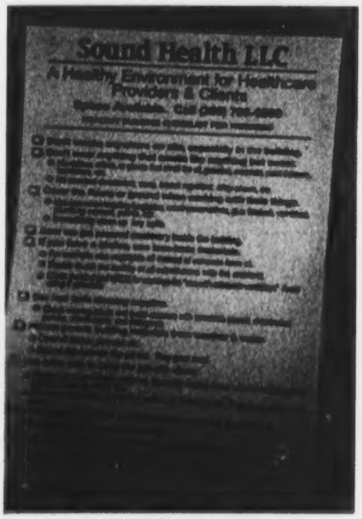
California Integrated Waste Management Board (CIWMB) web site provides links to many resources including the Clean Washington Center's *Recycling Plus Manual.* See http://www.ciwmb.ca.gov/ConDemo/Links.htm. Use this resource to produce a step-by-step construction waste management and recovery plan.

CIWMB, *Designing with Vision: A Technical Manual for Material Choices in Sustainable Construction.* Chapter 9, Managing Job-Site Waste addresses C&D waste. Located at http://www.ciwmb.ca.gov/ConDemo/Pubs.htm.

U.S. EPA, *Characterization of Building-Related Construction and Demolition Debris in the United States*, June 1998 at http://www.epa.gov/epaoswer/hazwaste/sqg/demol.htm. Provides national data that a builder may find helpful to estimate and characterize his own waste generation.

For product substitutions, refer contractors to the CIWMB web site. Also to *Green Spec: The Environmental Building News Product Directory and Guideline Specifications* (http://www.buildinggreen.com), and OIKOS web site (http://www.data.oikos.com/products). Also reference product information provided in building component sections in this document.

# Guideline GC3: Indoor Air Quality During Construction



*Healthy Job Site Signage. Photo courtesy of O'Brien & Company*

### Recommendation

Require indoor air quality planning and preventive job-site practices.

### Description

Preventive job-site practices can prevent residual problems with indoor air quality in the completed building and reduce undue health risks for workers. "Healthy" job-site planning will adequately address problem substances, including: construction dust, chemical fumes, off-gassing materials, and moisture; it will make sure these problems are not introduced during construction, or, if they must be, eliminates or reduces their impact. Areas of planning will include product substitutions and materials storage, safe installation, proper sequencing, regular monitoring, and safe and thorough cleanup.

### Applicability

Maintaining healthy job-site conditions is important for all spaces and all climates. The activity is carried out in the construction phase, but must be planned in the design development and contract documents phases.

| Applicable Spaces | | Climates | | When to | |
|---|---|---|---|---|---|
| Classrooms | ■ | South | ■ | Programming | ☐ |
| Library | ■ | North | ■ | Schematic | ☐ |
| Multi-Purpose / Gym | ■ | Central | ■ | Design Dev. | ▨ |
| Corridors | ■ | Mountains | ■ | Contract | ▨ |
| Administration | ■ | Desert | ■ | Construction | ■ |
| Toilets | ■ | | | Commissionin | ☐ |
| Other | ■ | | | Operation | ☐ |

### Applicable Codes

Local school districts are beginning to develop IAQ policies that incorporate construction operational requirements. See for example, the Materials/Indoor Air Quality Policy for School District Buildings, 1994-1995. Berkeley Unified School District, Berkeley, CA. Check with local jurisdiction to see if a similar policy in place. In addition, the U.S. Green Building Council's LEED Green Building Rating System (Commercial, Version 2) includes a provision for an IAQ construction plan. This provision requires that the project contractor "meet or exceed the minimum requirements of the Sheet Metal and Air Conditioning National Contractors Association (SMACNA) IAQ Guidelines for Occupied Buildings Under Construction, 1995."

### Integrated Design Implications

When identifying "healthy" materials for use in buildings, the focus is generally on preventing problems during occupancy. This guideline implies some responsibility for air quality during installation. This may impact the choice of material and/or the method of installation. Also, since substitutions may happen in the field due to availability and scheduling requirements, it will be important to layout out the approval process for these substitutions clearly. For materials with off-gassing potential, require specific ingredient information about the product itself (as well as any adhesives, solvents, or other products that might be used during installation or maintenance). Designing to use mechanical fasteners (screws, Velcro) rather than chemical adhesives and solvents can reduce potential problems with indoor air quality during construction.

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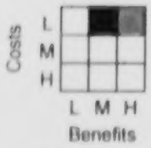
## Costs

Implementing this guideline should not necessarily add cost to the project. The one area it might add cost is in the form of potential delays due to sequencing and ventilation requirements. However, this cost can be avoided by proper planning.



## Benefits

The costs of poor indoor air quality are difficult to quantify, but considerable. They are the sum of illness and decreased student productivity paid by students and teachers, along with the district's cost of equipment replacement, workers compensation claims, and in the most severe cases, potential litigation. Unfortunately, serious health complaints have resulted from careless acts during construction projects, such as failure to clean up spilled adhesives or to properly ventilate during and after applying sealants in an occupied building. These mistakes have led to unpleasant headlines and costly lawsuits. Good IAQ strategies during construction will help eliminate these potential liabilities.

## Cost Effectiveness

Risk managers will be reluctant to take on the added responsibility of requiring indoor air quality planning and preventive job-site practices. However, school districts and project architects across the country have experienced litigation related to poor indoor air quality resulting from construction activities. Addressing these issues before and during construction will reduce exposure of the district and designers to potentially expensive litigation in the future.

## Design Tools

See electronic Appendix A for sample specification language.

## Design Details

Indoor air quality goals (as with all other sustainable building goals) should be outlined in the Instructions to Bidders as part of the Project Summary addition, indoor air quality specifications should be included in the Temporary Controls sections of General Conditions.

The specifications should: Describe what is included in an indoor air quality construction plan, outline submittal requirements, and reference the SMACNA IAQ Guidelines for Occupied Buildings Under Construction, 1995 to:

- Protect the ventilation system components from contamination, or provide cleaning of the ventilation components exposed to contamination during construction prior to occupancy.
- Provide a continuous ventilation rate of one air change per hour minimum during construction, or, conduct a building flush-out with new filtration media at 100% outside air after construction ends (following issuance of Occupancy Certificate) and prior to occupancy for seven days (one week). Provide a minimum of 85% filtration (as determined by ASHRAE Standard 52.1-1992) on any return air systems operational during construction, and replace filtration media prior to occupancy. Designers please note: Seven days is considered a minimum. Indoor Air Quality specialists recommend flushing the building with 100% outside air for 30 days prior to substantial completion.

If the contractor is required by the specification to be responsible for protecting indoor air quality during construction, it is not necessary to detail methods by which the contractor can achieve it. However, it is informative for contractors to include a list of proven air quality protection strategies, such as:

- Supplemental (temporary) ventilation during installation of carpet, paints, furnishings, and other VOC-emitting products, for at least 72 hours after work is completed. Preferred HVAC system operation uses supply air fans and ducts only; exhaust provided through windows. Use exhaust fans to pull exhaust air from deep interior locations. Stair towers and other paths to exterior can be useful during this process.

- Regular inspection and maintenance of indoor air quality measures including ventilation system protection, and ventilation rate.
- VOC-safe masks for workers installing VOC-emitting products (interior and exterior) defined as products that emit 150 gpl or more unless local jurisdiction's requirements are stricter, in which case the strictest requirement shall be followed for use of VOC-safe masks.
- Low-toxic cleaning supplies for surfaces, equipment, and worker's personal use. Options include several soybean-based solvents and cleaning options (SoySolv) and citrus-based cleaners.
- Wet sanding for gypsum board assemblies. Exceptions should be clearly defined and include: full isolation of space undergoing finishing or closure of all air system devices and ductwork. Additional conditions can be set.
- Safety meetings, signage, and subcontractor agreements that communicate the goals of the construction indoor air quality plan.

The indoor air quality construction plan is also a good opportunity to proscribe behaviors unacceptable to the owner that represent a potentially negative impact on long term indoor air quality such as smoking, using chew tobacco, or wearing contaminated work clothes.

### Operation and Maintenance Issues

Contractors should be required to provide information on product substitutions sufficient to enable O&M staff to properly maintain and repair low-emitting or otherwise "healthy" materials in place.

### Commissioning

Not applicable.

### Example(s)

Ross Middle School. Ross School District. Completed1999. For more information contact Dana Papke, DPapke@CIWMB.ca.gov.

### References/Additional Information

See the U.S. Green Building Council's *Reference Manual* for LEED Green Building Rating System (Commercial, Version 2) at http://www.usgbc.org. Also see Carpet and Rug Institute (CRI) guidelines for carpet installation. The Painting Contractors Union (New York City local) has reportedly developed guidelines for ventilation during painting.

For product substitutions, refer contractors to *Green Spec: The Environmental Building News Product Directory and Guideline Specifications* (http://www.buildinggreen.com), and OIKOS web site (http://www.data.oikos.com/products). Also reference product information provided in building component sections in this document.

# Guideline GC4: Site Protection During Construction

## Recommendation

Require best management practices for site protection during construction.

*Silt Fencing for Sedimentation Control. Photo courtesy of O'Brien & Company*

## Description

An effective job-site protection plan will describe construction practices that eliminate unnecessary site disturbance, minimize impact of the site's natural (soil and water) functions, and eliminate water pollution and water quality degradation. Primarily it will include protocols for construction equipment operation and parking, topsoil and vegetation protection & reuse, hazardous materials management, and installation and maintenance of erosion control and stormwater management measures.

## Applicability

This guideline applies to all climates and spaces.

| Applicable Spaces | |
|---|---|
| Classrooms | ■ |
| Library | ■ |
| Multi-Purpose / Gym | ■ |
| Corridors | ■ |
| Administration | ■ |
| Toilets | ■ |
| Other | ■ |

| Climates | |
|---|---|
| South | ■ |
| North | ■ |
| Central | ■ |
| Mountains | ■ |
| Desert | ■ |

| When to | |
|---|---|
| Programming | ☐ |
| Schematic | ☐ |
| Design Dev. | ▨ |
| Contract | ▨ |
| Construction | ■ |
| Commissionin | ☐ |
| Operation | ☐ |

## Applicable Codes

All jurisdictions include some requirements related to water quality protection, in particular stormwater management and erosion control during construction. Local policies may govern other construction activities covered in this Guideline. Please check with your local jurisdiction.

## Integrated Design Implications

The plan should be integrated with stormwater management and erosion control measures (see Site Planning). In addition, a requirement to submit ingredient information about in-field product substitutions to avoid degradation of water quality on the site will be important.

## Costs

This guideline recommends going beyond typical site practices. Redundant erosion control measures and stepped up maintenance inspections may add cost. The cost will depend significantly on the specific erosion control measures selected. On the other hand, least toxic pest and weed control should provide savings.

| Costs \ Benefits | L | M | H |
|---|---|---|---|
| L | ☐ | ☐ | ▨ |
| M | ☐ | ☐ | ■ |
| H | ☐ | ☐ | ☐ |

## Benefits

Construction delays and work stoppages due to erosion control failure can be avoided. Water quality in surrounding waterways and groundwater supplies are protected. Health risks to students due to residual toxicity on the site can be reduced.

## Cost Effectiveness

The project architect needs to evaluate the risk of erosion problems to determine whether redundant erosion control measures are cost effective. Least toxic pest and weed control is quite cost effective, as it can provide savings and an increased level of safety for students who will be using the school grounds.

## Design Tools

See electronic Appendix A for sample specification language.

## Design Details

Site protection (as with all other sustainable building goals) should be outlined in the Instructions to Bidders as part of the Project Summary In addition, site protection specifications should be included in the Temporary Controls sections of General Conditions. The specifications should: Describe what is included in a site protection plan, outline submittal requirements, and describe recommended strategies, including:

- Regular inspection and maintenance of site protection measures. Minimally, inspection of all erosion and sedimentation measures after a heavy rainfall, defined as ½ inches in less than 24 hours.
- Redundant mechanisms for site protection of any critical or sensitive areas on site, as identified in Site Plan. Silt fencing fabric and other temporary site protection measures should be selected to last for the life of the project.
- Measures to ensure that detergent does not get into oil and sediment separator.
- Posted protocol for construction vehicles regarding parking and access on the site.
- Rocked heavy construction vehicle entrance and tire wash.
- Posted clean-up procedures for spills to prevent illicit discharges.
- Measures to minimize risk of toxic release of hazardous wastes, including paints and other finish products, solvents, adhesives, and oils as follows:
- Avoid overstocking
- Adopt a first-in, first out policy
- Label containers properly
- Control access to storage areas and routinely inspect containers
- Inspect all containers upon receipt. Reject leaking or damaged containers.
- Topsoil preparation, planting, and maintenance using Integrated Pest Management (least toxic) protocol. Least-toxic products for controlling pests and insects in detention ponds and for soil prep. No chemical weed eradication.
- Safety meetings, signage, and subcontractor agreements that communicate the goals of the site protection plan.

## Operation and Maintenance Issues

O&M staff should be informed that least-toxic products have been used for soil preparation and for controlling pests and insects in detention ponds. In addition, contractors should be required to provide information on product substitutions sufficient to enable O&M staff to properly maintain site protection measures.

## Commissioning

Not applicable.

## Example(s)

Ross Middle School. Ross School District. Completed, 1999. For more information contact Dana Papke, DPapke@CIWMB.ca.gov.

## References/Additional Information

See the U.S. Green Building Council's *Reference Manual* for LEED Green Building Rating System (Commercial, Version 2) at http://www.usgbc.org. Also see the Environmental Protection Agency (EPA) publication:

For product substitutions, refer contractors to *Green Spec: The Environmental Building News Product Directory and Guideline Specifications* (http://www.buildinggreen.com), and OIKOS web site (http://www.data.oikos.com/products). Also reference product information provided in building component sections in this document.

# Guideline GC5: Contractor's Commissioning Responsibilities

## Recommendation

Require that the contractor provide the commissioning agent (CA) with information needed to facilitate the commissioning (Cx) process and to coordinate activities with the CA as needed.

## Description

Commissioning is a systematic, documented process including visual examination and functional performance testing to demonstrate that installed components or systems and the building coverall meet the intent of the original design. A CA is someone qualified to provide an independent inspection of the building or site/landscape component or system being commissioned. This guideline recommends that the contractor be required to coordinate with the CA and provide information as needed to optimize commissioning results. Contractors will be involved in fine-tuning and correcting systems when commissioning indicates this is needed.

The Five Phases of Building Commissioning

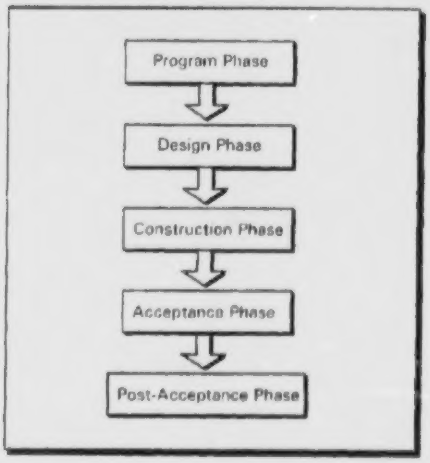
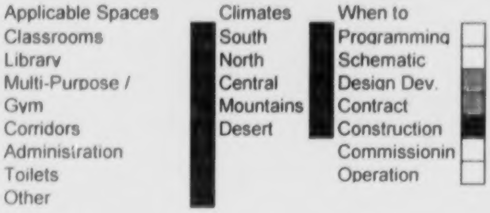


Figure 2-1 from Building Commissioning Guide (See References/Additional Information)

## Applicability

This requirement is applicable to all climates and spaces. It is implemented in the construction phase, but needs to be considered in both the design development and contract documents phase.



Applicable Spaces
Classrooms
Library
Multi-Purpose / Gym
Corridors
Administration
Toilets
Other

Climates
South
North
Central
Mountains
Desert

When to
Programming
Schematic
Design Dev.
Contract
Construction
Commissionin
Operation

## Applicable Codes

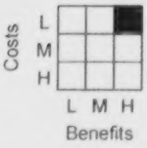
None.

## Integrated Design Implications

None.

## Costs

Costs for this aspect of commissioning are minimal. (Overall, commissioning has the potential for producing savings in avoided delays and other startup problems.)



## Benefits

Requiring contractor coordination will facilitate effective commissioning. Commissioning can provide tremendous economic benefits as well as improve building performance.

## Design Tools

Not applicable.

### Design Details

Commissioning goals (in addition to all high performance building goals) should be outlined in the Instructions to Bidders as part of the Project Summary. A requirement that the contractor coordinate with the CA should be included in General Conditions. (A separate commissioning agreement will be drawn up between the owner and the CA). Other commissioning requirements for the contractor will appear in pertinent sections, including mechanical (15) and electrical (16). (If the contractor is responsible for hiring the CA, there would a special section incorporating commissioning requirements, and the "coordination" aspect of this Guideline would be part of the agreement between the contractor and the CA.)

The contractor should be informed of the types of systems that will be commissioned, the types of information that may be required, and his responsibilities in terms of correcting problems that are identified. Types of systems to be commissioned may include:

- HVAC plant
- Air and water delivery system
- Energy management system
- Electrical and lighting system
- Fire/life safety system
- Data networks/communications
- Security system
- Irrigation system
- Kitchen equipment
- Building envelope
- Renewable energy system
- Fume hoods
- Science lab gas delivery system
- Emergency power supply
- Plumbing

Frequently it is difficult to enforce the requirement the Contractor finish all commissioning tasks prior to Substantial Completion. A practical solution is to provide an incentive to complete the work, by applying a penalty if such tasks are not performed by "functional" completion. (Exceptions would be seasonal or "approved deferred" testing and controls training. Functional and substantial completion should be defined in the general conditions of the construction contract.)

During construction, building systems are installed, undergo pre-functional performance tests and placed into operation. Once construction is completed, all building systems should be operating as designed, both individually and collectively, and are ready for functional performance testing. The contractor assists in all aspects of the commissioning process, including documentation, pre-functional testing, start-up and initial checkout, initial controls checkout, testing, adjusting and balancing (TAB), functional testing for individual systems and integrated systems, verification, training of O&M personnel, O&M manual development and review. In practice, some of the system checks included in full commissioning are often performed, but they are rarely documented.

### Operation and Maintenance Issues

The contractor will be required to provide documentation and information for the Cx process that will be incorporated into an O&M plan or manual.

### Commissioning

Not applicable.

### Example(s)

Capitol East End Complex. For more information, contact Eley Associates, (415) 957-1977.

Offices for State Department of Education.

**References/Additional Information**

DOE's Federal Energy Management Program (FEMP), in cooperation with the General Services Administration, developed the *Building Commissioning Guide* as part of GSA's facility commissioning program to ensure that construction of new facilities meets the requirements. Chapter 10 of this document is an extensive list of additional resources related to building commissioning. Version 2.2 of the Guide, along with *Model Commissioning Plan and Guide Specifications* and sample functional tests and checklists can be downloaded from FEMP's web site at: http://www.eren.doe.gov/femp/techassist/bldgcomgd.html.

A web site dedicated to providing access to documents dealing with the Guidelines for Total Building Commissioning is being developed under the auspices of the National Institute of Building Sciences. The site is maintained by the Florida Design Initiative and is organized around the individual technical guidelines that will comprise the complete set of Guidelines for Total Building Commissioning. http://sustainable.state.fl.us/fdi/edesign/resource/totalbcx.

The University of Washington offers a commissioning guide in its Facility Design Information Manual, much of which can be applied to K-12 schools. Available at http://depts.washington.edu/fsesweb/fdi.

*Implement Building Commissioning,* published by U.S. Department of Energy, Rebuild America, EnergySmart Schools program (Washington, D,C., 2000 ); available at http://www.eren.doe.gov/energysmartschools/om_implement.html. Defines building commissioning; discusses the selection of a commissioning agent; the benefits, approaches, and components of commissioning; and lists resources.

*Sustainable Building Technical Manual: Green Building Design, Construction, and Operations,* produced by Public Technology, Inc., U.S. Green Building Council (USGBC), and U.S. Department of Energy, with support from EPA, 1996. See Chapter 15, "Building Commissioning." Available from USGBC, San Francisco, CA; tel: 415-445-9500 or download at http://www.sustainable.doe.gov/pdf/sbt

# SITE PLANNING

This chapter provides guidelines for:

Designing for optimum building orientation (Guideline SP1)

Using landscaping to provide shading for buildings and paved areas (Guideline SP2)

Designing for safe, energy-efficient transit (Guideline SP3)

Designing landscapes with vegetation, infrastructure and natural lawn care (Guideline SP4)

Minimizing impervious surface areas (Guideline SP5)

Landscaping with drought-tolerant and pest-resistant plants (Guideline SP6)

Considering shading and air quality when positioning HVAC equipment (Guideline SP7)

Using recycled content products for landscaping accessories (Guideline SP8)

Using soil amendments and mulch to restore the health of disturbed soils (Guideline SP9)

Installing water-efficient irrigation systems (Guideline SP10)

Managing stormwater and materials-efficient drainage (Guideline SP11)

Using reclaimed water (Guideline SP12)

Designing and managing for the use of integrated pest management (IPM) (Guideline SP13)

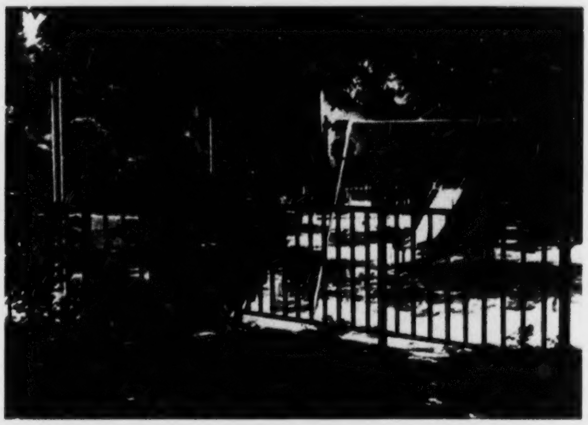
Managing groundwater separately from surface water (Guideline SP14)

Providing on-site wastewater treatment (Guideline SP15)

## Overview

> "Letting the land and nature do the site planning is always less expensive…and climatically appropriate siting and materials choices results in buildings and infrastructure that will last longer."
>
> —John Knott, developer of Dewees Island, the first development honored for environmental sensitivity by the President's Council on Sustainability

Site planning for a high performance school project takes into account issues that go beyond those traditionally considered for the design and construction of schools. Sustainable site planning respects and works with the natural processes of the land. It adapts the development components—buildings, utilities, site amenities and infrastructure—to the patterns of the place, and requires investigation and analysis of the site and the surrounding neighborhood.



*Berkeley, CA. Good separation between growth and high-use play areas have created a complex and vibrant playground. Photo courtesy Wolfe Mason Associates.*

Sustainable site planning addresses environmental, social and economic objectives to create a high performance school that is not only energy efficient but also a community resource with amenities for a quality education. Ideally it provides a nurturing environment that is well lit, comfortable, healthy and compatible with the natural ecosystems of the area.

Many traditional school sites in the past replaced natural landscapes with flat sterile outdoor spaces consisting only of asphalt and metal climbers. Vegetation, if allowed, was kept to orderly rows of shrubs at the foundation of the buildings or an open expanse of mowed turf. High performance schools are community facilities that can change this pattern of site design and should lead by example.

### Benefits of Sustainable Site Planning and Design

The choices made during site planning affect the entire spectrum of high performance goals. Table 2 summarizes many of these site planning considerations.

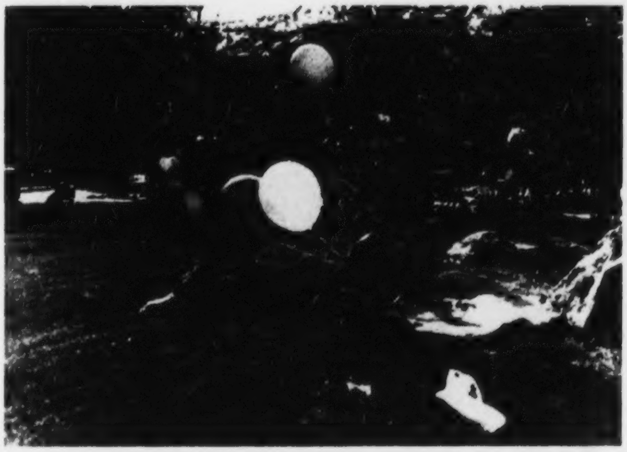
*Table 2 – Site Planning Considerations*

| Goal | Site Planning Considerations |
|---|---|
| Energy Efficiency | Energy efficiency through effective building location, orientation and massing, and the placement of vegetation for shade or wind protection. |
| Water Efficiency | Water-efficient plant materials and landscaping design that can survive and evolve with intensive use.<br>Responsible water management through the creative use of cisterns, green roofs, gray water systems, vegetated swales and ponds, etc. |
| Protection of the Natural Ecosystem | The majority of site planning decisions will directly affect the overall level of impact to the natural environment: water conservation, treatment of surface water, building orientation, preservation and restoration of natural habitats, use of native plants and appropriate landscaping materials, etc. |
| Material Efficiency | Waste stream awareness and development of interactive systems for trash, recycling, composting, reducing packaging, waste water, etc.<br>Use of salvaged landscaping materials or those made from recycled materials. |
| Acoustic, Thermal and Visual Comfort | Reduction of the heat island effect and need for air conditioning by minimizing hard surfaces to essential zones or combining hard surfaces for multiple uses; using trees or shade structures; using paving materials that help return water to the ground.<br>Orientation of windows, reflective surfaces and potentials for visual and thermal comfort.<br>Relationship of buildings, especially classrooms, to sources of noise such as roadways for acoustic comfort. |
| Health and Indoor Air Quality | Opportunities for natural ventilation; reduction of carbon dioxide by vegetation. |
| Security and Safety | Site safety and security by the placement of buildings and landscaping, the use of protected courtyards, and well situated access and circulation points. |
| Connection to Neighborhood and Surrounding Community | Connection to the surrounding neighborhood through community gardens, school parks, meeting rooms, multi-use facilities such as day care, laundry, café, etc.<br>Partnerships with local nonprofit organizations for fundraising, maintenance, events, shared facilities, etc.<br>Involvement of students, parents, faculty and neighbors in learning about ecological design during the planning process, classes and curriculum in the outdoor spaces and through ongoing site monitoring and adaptation. |
| Learning | Use of nature as a teaching tool for science, history, art and health programs; use of gardens connect students to the earth and the cycle of life, as well as providing opportunities to grow food and herbs. Potential opportunities for real-life lessons in businesses and economics through on-site programs involving growing and selling or trading products. |
| Playing | Creative play areas utilizing a wide variety of natural elements. Consider a schoolyard landscape with areas with soil, water and "critters," rather than simply formal, planted hedges and groomed turf. |

## Sustainable Site Planning Process

The sustainable site planning process is cyclical, interactive and adaptive. It is flexible and adaptable to both small and large projects. It integrates and balances ecological, social and economic needs. It emphasizes long-term, cost-effective strategies over immediate short-term results. And it is an open and inclusive process that relies on broad-based public, interdisciplinary and interagency participation.

Sustainable site planning begins with developing an understanding of a potential site by assessing existing ecological conditions including geology and soil type; topography and aspect; water amount, flow and quality; vegetation and habitat; and climate and microclimate. Additional site assessment elements to consider include service areas for the school, boundary and edge conditions of the site; access and circulation; size and shape of the site; ancillary spaces in the school building or freestanding accessory structures; and construction materials, tools and staffing. During this initial assessment, the program needs of students, teachers, parents, administrators and the surrounding neighborhood should be elicited. Also, evaluate proximity to transportation not just with regard to safety and convenience, but also with consideration for energy efficiency and air pollution impacts. Keep in mind that redevelopment of a site or extensive renovations of an existing school have added value because such projects preserve undeveloped land elsewhere.



*Berkeley, CA. Boulders add interest and alternative play areas for these children. Mulch filled cutouts protect tree roots from mowing damage. Photo courtesy Wolfe Mason Associates.*

Once a site is selected, use educational specifications and the schematic design to highlight and specifically address areas of the site targeted for conservation or enhancement of the natural environment. In addition, select and specify environmentally preferable site materials. These include building products that use raw materials efficiently and do not introduce pollutants or degradation to the project site or atmosphere, and building systems that conserve water and energy. (For additional information about materials see, see the Materials Efficiency and Material Selection and Research in the Introduction to Volume II.) All stakeholders should meet to review the baseline data and discuss the opportunities and constraints based upon the initial site analysis and program. These stakeholders help define the project's "vision," which guides development of the plan. Their involvement is essential throughout the planning and design process. The plan, developed by the design team and approved by the community, might include many or all of these principles:

- Identify and protect existing natural features and ecosystems.
- Repair and restore damaged natural areas and create habitat to promote biodiversity.
- Respect and incorporate historic, cultural and artistic resources.
- Manage water on the site to absorb the water, capture runoff and reduce pollution.
- Create healthy landscapes that evolve over time and survive intensive use.
- Develop a responsible maintenance and management program that incorporates an objective monitoring and evaluation strategy.
- Provide a strong link to the surrounding neighborhood and become an active part of the community.

## Design Goals and Guidelines

Site planning activities for a high performance school seek to achieve one or more of the following three primary goals:

1. Protect and/or restore the site
2. Incorporate the site's natural features to achieve high performance
3. Select environmentally preferable products

## Protect and Restore the Site

The natural functions of a site (hydrologic, geologic and micro-climatic) can be seriously disrupted by the construction and operation of a building. The design of a high performance school will consider ways that natural site features can be protected—perhaps even restored—through the design, development and construction processes. For example, preserving natural vegetation reduces overall disturbance to the site. Soil amendments help restore the health of disturbed soils. And designing to reduce impervious surfaces mitigates stormwater runoff caused by construction and protects the hydrologic functions of the site.

Site protection and restoration objectives include:

- Minimizing disturbance to the site
- Mimicking (or restoring) natural processes in disturbed areas
- Protecting water quality

## Incorporate the Site's Natural Features to Achieve High Performance

A high performance school responds to the site. Building placement, orientation, massing and layout decisions made early in the school design process can profoundly affect the energy impacts of the building. These decisions also bear on the resulting indoor environment since they either capture or lose opportunities for daylighting and natural ventilation. Other implications include acoustic comfort, safety, and visual quality. The design of a high performance school incorporates the site's natural advantages and features to achieve the school's high performance goals.

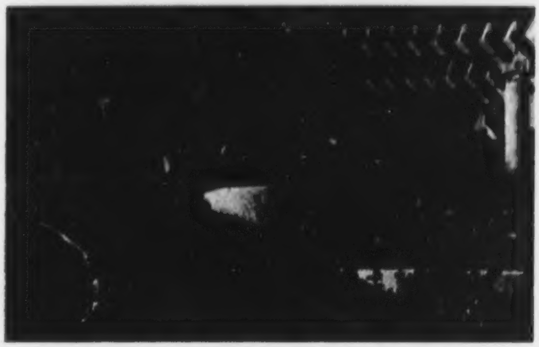
In addition, the high performance school site and building should be available to "teach" environmental protection concepts. Site design will take into consideration opportunities for outdoor classrooms and environmental learning projects. With careful planning and coordination with school staff, such projects can be identified and then facilitated during construction. For example, stream restoration by students and staff can take place more easily if a culvert has been removed during construction. Or a wetland graded during construction can be planted as part of lessons about the natural ecosystems.

Site planning objectives that fall into this category include:

- Reduce the demand for water

- Reduce energy demand

### Select Environmentally Preferable Materials



*Bloomington, MN. Natural landscaping materials separate landscaping zones of local plants, including native grasses that do not require mowing. Photo courtesy Wolfe Mason Associates.*

A steadily increasing number and variety of environmentally preferable products are available for sitework and landscaping. These products include landscaping accessories made with post-consumer and post-industrial recycled materials (parking stops, bike racks, tree cuffs, grates, landscaping ties, planters, outdoor furniture, and lighting and sign posts), recycled concrete asphalt aggregate for fill or road base, concrete made with flyash, and recycled content soil amendments. The selection of environmentally preferable materials has added benefit as a teaching tool. Prominent interpretive signage can inform students, staff, parents, and the community about environmentally preferable materials and their attributes.

Table 3 summarizes the site planning goals and objectives described above, and shows the correspondence of these objectives to the site planning guidelines provided in this chapter.

*Table 3 – Site Planning Goals and Relationship to Guidelines*

| **Site Planning Goal** | **Guideline** |
|---|---|
| *Objective/Strategy* | |
| **Protect and Restore the Site** | |
| *Minimize disturbance to the site* | Guideline SP6: Drought-tolerant and Pest-resistant Plants |
| | Guideline SP14: Groundwater Management |
| *Mimic natural process* | Guideline SP5: Impervious Surfaces |
| | Guideline SP9: Landscaping Soil, Amendments and Mulch |
| | Guideline SP14: Groundwater Management |
| | Guideline SP15: On-site Wastewater Treatment |
| *Protect water quality* | Guideline SP13: Integrated Weed, Disease and Pest Management |
| | Guideline SP14: Groundwater Management |
| | Guideline SP9: Landscaping Soil, Amendments and Mulch |
| **Incorporate the Site's Natural Features to Achieve High Performance** | |
| *Reduce water demand* | Guideline SP6: Drought-tolerant and Pest-resistant Plants |
| | Guideline SP4: Landscape Design & Management: Vegetation, Infrastructure and Natural Lawn Care |
| | Guideline SP10: Water-efficient Irrigation Systems |
| | Guideline SP12: Reclaimed Water for Irrigation |
| | Guideline SP15: On-site Wastewater Treatment |
| | Guideline SP9: Landscaping Soil, Amendments and Mulch |
| *Reduce energy demand* | Guideline SP2: Landscaping to Provide Shade to Buildings and Paved Areas |
| | Guideline SP7: Location of HVAC Equipment |
| | Guideline SP3: Safe and Energy Efficient Transportation |
| | Guideline SP1: Optimum Building Orientation |
| **Select Environmentally Preferable Materials** | |
| | Guideline SP8: Landscaping Accessories |
| | Guideline SP11: Stormwater Management and Drainage Materials |
| | Guideline SP5: Impervious Surfaces |
| | Guideline SP9: Landscaping Soil, Amendments and Mulch |

## Resources

Architects, Designers and Planners for Social Responsibility (ADPSR) West Coast. 1998. *Architectural Resource Guide.* Contact: ADPSR, PO Box 9126, Berkeley CA. Tel: (510) 273-2428. Resources and information on green and healthy buildings, including many sources for materials in California.

Barnett, D.L. 1995. *A Primer on Sustainable Building.* Snowmass, CO: Rocky Mountain Institute. Web site: http://www.rmi.org. An excellent overview of issues and benefits of sustainable building.

Center of Excellence for Sustainable Development, U.S. Department of Energy, Energy Efficiency and Renewable Energy Network (EREN). Provides web pages on green building and green development. Web site: http://www.sustainable.doe.gov.

Crowther, R.L. 1992. *Ecological Architecture.* Boston: Butterworth Architecture. Primer on ecological design, emphasizing the importance of holistic building design and its integration with natural systems. Includes design guidelines for design, landscaping and planning.

King County, Washington. *Construction and Landscaping Materials Specifications.* Available at http://www.metrokc.gov/procure/green/const.htm.

Los Angeles, City of. *Sustainable Building Reference Manual.* Contact: Nady Maechling. Tel: (213) 473-8226. Contains a lot of local information and resources.

Lyle, J.T. 1994. *Regenerative Design for Sustainable Development.* New York: John Wiley & Sons. One of the seminal books on the theory, design and construction of regenerative systems and the practical application of ecological design.

Marsh, W. M. 1991. *Landscape Planning: Environmental Applications.* New York: John Wiley & Sons. A definitive reference for landscape architects, planners and designers on the definition and application of environmental design principles to landscape and site planning.

Maryland State Department of Education. *Conserving and Enhancing the Natural Environment, A Guide for Planning, Design, Construction, and Maintenance on New & Existing School Sites* and *Building Ecology and School Design.* 1999. To order, contact the Maryland State Department of Education, Division of Business Services, School Facilities Branch, 200 W. Baltimore St., Baltimore, MD 21201. Phone for Capital Projects Assistant Manager: (410)-767-0097

Mason, Gary et al; *An Ecosystem-based Approach to Planning Communities: An Ecosystem Manager's Workbook*, USDA Forest Service, Center for Urban Forestry, 1994, 1996, 1998.

Mason, Gary et al; *An Ecosystem-based Approach to Planning Communities: An Ecosystem Manager's Workbook*, USDA Forest Service, Center for Urban Forestry, 1994, 1996, 1998.

Moore, Robin C. and Wong, Herb H.1997. *Natural Learning: Creating Environments for Rediscovering Nature's Way of Teaching*, MIG Communications.

Rocky Mountain Institute.1998. *Green Development: Integrating Ecology and Real Estate.* New York: John Wiley & Sons.

*Second Nature: Adapting Los Angeles's Landscape for Sustainable Living.* 1999. Published by TreePeople.

Sorvig, K. 1996. *Sustainable Building Technical Manual.* Washington DC: Public Technologies Inc. Chapter 7, Site Materials and Equipment, offers a concise, valuable overview that highlights design considerations for soil amendments, plant materials and management, paving materials and materials for site construction and furnishings.

Spurgeon, Richard. 1988. *Ecology: A Practical Introduction with Projects & Activities.* Osborne Publishing Ltd.

For additional information about environmentally preferable materials, see the Material Selection and Research section in the Introduction to Volume II.

## Acknowledgments

The following resources were particularly useful for developing this chapter on site planning:

Green Building Task Force. The Green Building Task Force was formed by a number of state agencies to institutionalize sustainable building practices into state construction projects. The task force meets on a monthly basis to discuss strategies for implementing sustainable building practices in all future and current state buildings, including those leased by the State. See http://www.ciwmb.ca.gov/greenbuilding/partnerships/default.htm for more information and links to member agencies.

Santa Monica, City of. 1999. *Santa Monica Green Building Design and Construction Guidelines.* Available online at http://greenbuildings.santa-monica.org/main.htm.

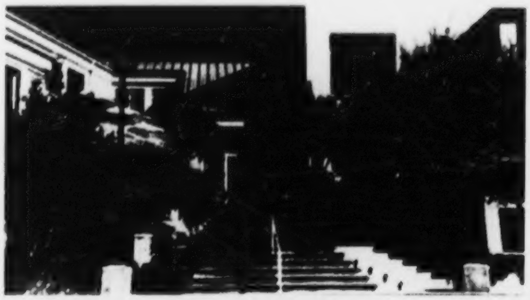
Partnership for Resource-Efficient Schools. 1998. *Recommended Best Management Practices Promoting Energy Efficiency, Resource Conservation, and Environmental Quality.* A publication of the Seattle Public Schools Building Excellence Program and the City of Seattle (Solid Waste Utility, Water Department and Seattle City Light). The following web site provides information about the Partnership for Resource-Efficient Schools project and a link to download the Best Management Practices manual: http://www.cityofseattle.net/util/rescons/susbuild/partnership.htm

BUILT GREEN™ Handbook. 1999. BUILT GREEN is a program of the Master Builders Association of King and Snohomish Counties (MBA) in partnership with King County, Washington and Snohomish County, Washington. http://www.builtgreen.net/.

# Guideline SP1: Optimum Building Orientation

## Recommendation

When site conditions permit, orient buildings so that major windows face either north or south. Position classrooms so that light and air can be introduced from two sides. Solar orientation should guide the placement of building and site features.



*Oakland, CA. Orientation plays a key role in the landscaping and daylighting design; low walls, building materials, and varied landscaping create a rich and inviting entrance. Photo courtesy Wolfe Mason Associates.*

| Applicable Spaces | | Climates | | When to Consider | |
|---|---|---|---|---|---|
| Classrooms | ■ | South Coast | ■ | Programming | ■ |
| Library | ■ | North Coast | ■ | Schematic | ■ |
| Mulit-Purpose / Cafeteria | ■ | Central | ■ | Design Dev. | ■ |
| Gym | ■ | Mountains | ■ | Contract Docs | ☐ |
| Corridors | ■ | Desert | ■ | Construction | ☐ |
| Administration | ■ | | | Commissioning | ☐ |
| Toilets | ■ | | | Operation | ☐ |
| Other | ■ | | | | |

## Description

Space heating and cooling accounts for nearly 20% of all energy consumption in the United States. Optimal orientation of the building creates opportunities to utilize the potential contributions of the sun, topography, and existing vegetation for increased energy efficiency by maximizing heat gain (or minimizing heat loss) in winter and minimizing heat gain in summer. In the case of existing buildings, arrangement of interior spaces, strategic landscaping, and modifications to the building envelope can mitigate unfavorable orientation.

## Applicability

All climates. Primarily for new buildings and site planning, with some applicability to retrofitting existing buildings for greater efficiency.

## Applicable Codes

None.

## Integrated Design Implications

Knowledge of the existing site soils, vegetation and microclimate are critical to understanding how to best arrange site elements to create the least disruption to the site and orient structures and spaces appropriately. Integrate existing site features; proposed landscape design; orientation, height and finish of walls; architectural design; impervious surfaces; location of heating and cooling equipment. Refer to guideline: SP3: Safe and Energy Efficient Transportation and SP2 Landscaping to Provide Shade to Buildings and Paved Areas.

## Costs

Cost implications exist mainly in the design phase. Resulting cost savings will be demonstrated during building operation with lowered heating and cooling requirements.

| Costs | L | M | H |
|---|---|---|---|
| L | | | ■ |
| M | | | |
| H | | | |
| | Benefits | | |

## Benefits

Reduced energy consumption will result in cost savings for year round heating and cooling. The arrangement of interior and outdoor spaces with thoughtful solar orientation allows optimal natural lighting and user-friendly spaces.

## Design Tools

PG&E and Edison offer use of heliodons for accurate modeling of daylighting effects. Contact their energy centers for more information. A physical model is mounted on the heliodon and a simulated sun shows shadows and solar exposure for different times of the day and the year. Most are coupled with a video camera for recording the test.

The Libby-Owens Ford Sun Angle calculator is a handy tool for studying sun position for different times of the day and year. It can be used to determine the required distance between buildings needed for adequate solar exposure and for determining the effect of shading obstructions such as adjacent buildings.

## Design Details

Consider east-west orientation to maximize north-south daylighting opportunities. Single story designs offer top-lighting daylight strategies for all spaces. Keep width of building to less than 60' to increase daylight and ventilation opportunities.

Timesaver Standards for Landscape Architects describes site planning and building orientation in the following:

- Plan site clearing and planting to take advantage of solar access. Solar orientation, cloud cover, and topography create unique site attributes. A site's latitude determines the sun's altitude and associated azimuth for a given time or day. Orient the building to take advantage of solar energy for passive and active solar systems. The building should take advantage of shade and airflows to maximize summer cooling and to optimize passive solar energy for heating and wind protection during winter months. Orient solar collectors for maximum sun exposure.
- Orient building-entrances and outdoor gathering spaces to maximize safety, ease of access, and protection from elements.

Solar angles, soils, and topography determine plant species and distribution, as well as vulnerability of the land to erosion by runoff. The extent of disruption to the site during construction can be minimized with careful orientation of buildings and site elements. Align long buildings and parking areas parallel to landscape contours.

## Operation and Maintenance Issues

None.

## Commissioning

N/A.

## Example

Durant Road Middle School, Wake County, NC

## References / Additional Information

American Institute of Architects Research Corporation. *Solar Dwelling Design Concepts.* Washington, D.C.: U.S. Department of Housing and Urban Development, 1976.

Buffo, John, et al. "Direct Solar Radiation on Various Slopes from 0 to 60 Degrees North Latitude." U.S.D.A. Forest Service Research Paper PNW-142, 1972, 74pp.

DeChiara,Joseph. *Site Planning Standards.* 1978. McGraw-Hill, Inc.

Harris, Charles. *Timesaver Standard for Landscape Architecture: Design and Construction Data.* 1998. McGraw-Hill, Inc.

Land Design/Research, Inc. *Energy Conserving Site Design Case Study,* Burke Center, Virginia. Washington, D.C.: U.S. Department of Energy, 1979, 60pp.

Marsh, W.M. *Landscape Planning: Environmental Applications.* 1991. John Wiley & Sons, New York.

Marsh, William M., and Dozier, Jeff. *"The Radiation Balance." In Landscape: An Introduction to Physical Geography.* Reading, MA: Addison-Wesley, 1981, pp. 21-35.

Sizemore and Associates. *Methodology for Energy Management Plans for Small Communities.* Washington, D.C.: U.S. Department of Energy, 1978.

Sterling, Raymond, et al. *Earth Sheltered Community Design.* New York: Van Nostrand Reinhold, 1981, 270 pp.

## Guideline SP2: Landscaping to Provide Shade to Buildings and Paved Areas

### Recommendation

Use landscaping to shade windows on the east and west facing building facades. Use landscaping or shade structures to shade paved areas to reduce the heat island effect.

*Berkeley, CA. **Arbors and trellises provide shade to ground and building surfaces for this daycare center.** Photo courtesy of Wolfe Mason Associates*

| **Applicable Spaces** | | **Climates** | | **When to Consider** | |
|---|---|---|---|---|---|
| Classrooms | ☐ | South Coast | ■ | Programming | ■ |
| Library | ☐ | North Coast | ■ | Schematic | ■ |
| Mulit-Purpose / Cafeteria | ☐ | Central | ■ | Design Dev. | ■ |
| Gym | ☐ | Mountains | ■ | Contract Docs | ☐ |
| Corridors | ☐ | Desert | ■ | Construction | ☐ |
| Administration | ☐ | | | Commissioning | ☐ |
| Toilets | ☐ | | | Operation | ☐ |
| Other | ■ | | | | |

### Description

Landscaping can greatly reduce the impacts of heavy radiation loads on the roof and east and west exposure in summer. In temperate regions, site planning and design should seek to promote shade and evaporative cooling in warm periods and block winds and promote heat gain in cool periods, without disrupting favorable summer wind patterns. In hot, arid regions, plan to balance daily temperature extremes by storing energy, increasing humidity, and diverting desiccating winds.

### Applicability

Building and site design.

### Applicable Codes

Some communities in California have a 51% shade canopy requirement for parking lots.

### Integrated Design Implications

Integrate landscaping, parking lot design and lighting design, irrigation, and preservation of existing plants with building design and orientation. Wind and moisture patterns should be considered during site planning in conjunction with goals to provide building shade. Design coordination will be needed so that trees and lighting are placed without conflicting with the shade or foot candle requirements. Shading and location of heating and cooling equipment should also be considered. Refer to guideline SP 4: Shade heat rejection equipment; SP3: Parking and Transportation; SP 15: Optimum Building Orientation.

### Costs

Costs will vary depending on the type and extent of vegetation or shading structures used.

Costs

| | | | |
|---|---|---|---|
| L | ■ | | |
| M | | | |
| H | | | |
| | L | M | H |

Benefits

### Benefits

Lower energy costs from reduced solar loads on building. Reduced heat islands due to shading and cooling effects of vegetation.

### Design Tools

Charts illustrating distance required between buildings or landscaping to avoid shadows and minimum spacing required to assure adequate light penetration. Solar path, latitude and altitude charts.

## Design Details

Building orientation should be closely integrated with landscape design. Planting deciduous trees on the Southeast, Southwest and West side of the building will reduce solar gain in summer during the morning and afternoon. Deciduous vines on arbor structures will provide shade, similarly, particularly when used adjacent to the building on the South or west face, sheltering the interior from summer midday sun while allowing solar penetration in winter. Plant low branching deciduous trees on the West side to keep low afternoon sun off west and north walls in summer.

If natural ventilation is used, lower branches of trees may have to be pruned to avoid obstructed air flows.

Consider the use of vines against south and west facing walls to reduce reflected and absorbed heat and light. This can reduce the temperatures in courtyards and outdoor spaces as well as adjacent buildings and interior spaces.

In urban environments, the site context may include solar windows (gaps between buildings) and shadow corridors (elongated zones which block the sun) which should be considered during site design to maintain sunlight to structures.

Parking lots and paved areas can reflect sunlight and absorb heat that raises temperatures. Shading with trees, shade structures or structures with vines can help lower temperatures.

## Operation and Maintenance Issues

Design criteria and maintenance guidelines will be needed so that trees shading parking lots and other paved areas can grow to full maturity without excessive pruning.

## Commissioning

N/A

## Examples

## References/Additional Information

*Landscape Planning: Environmental Applications.* Marsh, W.M. 1991. John Wiley & Sons, New York.

*Site Planning Standards.* DeChiara,Joseph. 1978. McGraw-Hill, Inc.

Timesaver Standard for Landscape Architecture: Design and Construction Data. 1998. Harris, Charles. McGraw-Hill, Inc.

# Guideline SP3: Safe and Energy Efficient Transportation

## Recommendation

Locate schools and design school sites to encourage use of safe, energy efficient transit alternatives and to discourage use of single-use automobile transportation.

Incorporate safe and effective parking and storage for bicycles, skateboards, rollerblades, scooters, etc.

## Description

Strategies for encouraging the use of safe, energy-efficient transportation alternatives include providing safe bike and pedestrian paths and providing facilities for shared vehicle transportation (carpools, vanpools, mass transit).

## Applicability

All climates.

## Applicable Codes.

Applicable municipal codes.

| Applicable Spaces | | Climates | | When to Consider | |
|---|---|---|---|---|---|
| Classrooms | ☐ | South Coast | ■ | Programming | ■ |
| Library | ☐ | North Coast | ■ | Schematic | ■ |
| Mulit-Purpose / Cafeteria | ☐ | Central | ■ | Design Dev. | ■ |
| Gym | ☐ | Mountains | ■ | Contract Docs | ■ |
| Corridors | ☐ | Desert | ■ | Construction | ■ |
| Administration | ☐ | | | Commissioning | ☐ |
| Toilets | ☐ | | | Operation | ■ |
| Other | ☐ | | | | |

## Integrated Design Implications

Start at the site selection and site planning stage. Then incorporate strategies into building and site design especially at access, circulation and parking lot design.

## Costs

Costs will vary with strategies selected. In most cases, additional costs are minimized when integrated early into site/building design. Added costs will be offset by reduction in parking lot size.

## Benefits

Reduced automobile use, reduced traffic congestion, improved urban air quality, improved sense of community, more efficient use of site (if parking lot size is reduced).

| | Benefits L | Benefits M | Benefits H |
|---|---|---|---|
| Costs L | ☐ | ■ | ▨ |
| Costs M | ☐ | ☐ | ☐ |
| Costs H | ☐ | ☐ | ☐ |

## Design Tools

IESNA. 1980. RP-8 Roadway Lighting, Chapter 4, Pedestrian Walkway and Bikeway Lighting Design, Illuminating Engineering Society of North America (IESNA), New York. This document contains guidelines for the design of fixed lighting for roadways, bikeways and pedestrian paths.

## Design Details

- Pedestrian and bike-friendly features include pedestrian paths and walkways, bike paths, safe and accessible bike storage, and showers/changing facilities.
- Good lighting is critical for safe walkways in the early morning and at night. Provide effective lighting onto walkways in accordance with illuminance levels and cut-off angles as specified by IESNAs RP8.

- Although cyclists and joggers can change in washrooms and store a change of clothes in the workplace, dedicated facilities are more likely to encourage regular human-powered commuting. Provide changing rooms, lockers and showers for employees. Connect changing room, shower and locker facilities with bicycle storage, or with washroom facilities, or pools. Provide sufficient showers to avoid waits at peak times, and to accommodate growing use. Provide separate change/shower rooms for males and females, possible. Caution: Facilities must be accessible to building occupants, but not to the general public or visitors.
- Building design can encourage car-pooling and vanpooling by giving priority to shared transportation, and by making waiting areas convenient and safe.
- Locate carpool and vanpool parking spaces closer to the building entrance than other single-use automobile parking.
- Post prominent signage to identify the location of carpool and vanpool parking and pick-up areas.
- Provide safe and comfortable waiting areas to encourage carpool and vanpool commuters. Consider amenities such as sunshades and rain canopies, seating and bulletin boards.
- Safety Cautions
- Ensure commuter safety with building lobbies that view waiting, pick-up and drop-off areas, occupied windows that overlook them, good lighting, and if necessary, prominent surveillance cameras. Eliminate potential hiding places for potential criminals.
- Ensure that sheltered areas are visible from the street and/or parking areas, sidewalk, and school building.
- Avoid creating small dark, courtyards that winter sun never reaches.
- Heavy and massive arcades and other features can obscure visibility and affect pedestrian safety.

Note: The cost premium for providing for energy efficient and environmentally safe transportation may be offset by grants offered by various agencies.

### Operation and Maintenance Issues

N/A

### Commissioning

NA

### Example(s)

### References/Additional Information

Bicycle Federation of America. (April 1999). Internet Resource Center. http://www.bikefed.org. Comprehensive coverage of a host of policy, planning and design guidelines supporting bicycle use.

Cox, E. (April 1999). Long Term Bike Parking. http://www. ips.net/cbc/longbikepark.html. Useful overview of design considerations for long-term bicycle storage offering essential and optional features for caged facilities, bike rooms, bike lockers and shower and clothes locker rooms.

Woodhull, J. 1992. *How Alternative Forms of Development Can Reduce Traffic Congestion*" Sustainable Cities; Concepts and Strategies for Eco-City Development, Ed. Bob Walter et al., Eco-Home Media, Los Angeles. Offers alternative approaches to traffic planning concentrating on "access" rather than mobility. Covers densification, parking, development patterns and offers solutions for pedestrian-friendly, transit-oriented development.

# Guideline SP4: Landscape Design & Management

## Recommendation

Develop a landscape design and management plan for vegetation, infrastructure and natural lawn care based on an ecological approach. Use this plan to guide site preparation, site design and ongoing care of the site.

## Description

A landscape design and management program for a high performance school includes objective plans, tasks, standards and requirements that provide information about how to create a healthy and attractive landscape. The plan should recognize the inherent characteristics of the site and surrounding region; and should seek to maximize resource conservation and recycling.

## Applicability

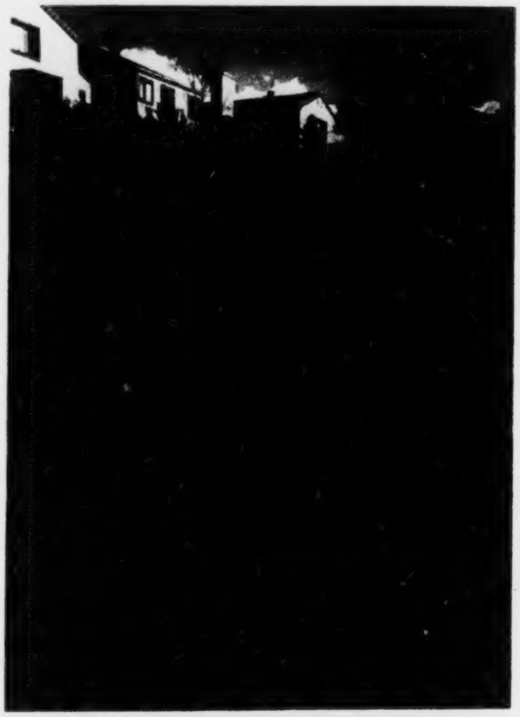
All climate regions.

## Applicable Codes.

Model Water Efficient Landscape Ordinance, Division 2, Title 23, California Code of Regulations, Chapter 2.7, Sections 490 through 495 (http://wwwdpla.water.ca.gov/cgi-bin/urban/conservation/landscape/ordinance/index), or applicable local ordinances.

## Integrated Design Implications

Planning for landscape management, including vegetation, infrastructure and natural lawn care, should be integrated and coordinated with Guideline SP13: Landscaping Soil, Amendments and Mulch, Guideline SP6: Drought-tolerant and Pest-resistant Plants, and Guideline SP13: Integrated Weed, Disease and Pest Management. All landscape planning should also take into account irrigation system parameters to help maximize water efficiency (see Guideline SP10: Water Efficient Irrigation Systems).



*Castro Valley, CA. Creeping red fescue covers this difficult to maintain site and does not require mowing. Grass is also appropriate for pedestrian traffic and general use. Photo courtesy of Wolfe Mason Associates.*

| Applicable Spaces | | Climates | | When to Consider | |
|---|---|---|---|---|---|
| Classrooms | ☐ | South Coast | ■ | Programming | ■ |
| Library | ☐ | North Coast | ■ | Schematic | ■ |
| Mulit-Purpose / Cafeteria | ☐ | Central | ■ | Design Dev | ▨ |
| Gym | ☐ | Mountains | ■ | Contract Docs | ▨ |
| Corridors | ☐ | Desert | ■ | Construction | ☐ |
| Administration | ☐ | | | Commissioning | ☐ |
| Toilets | ☐ | | | Operation | ■ |
| Other | ☐ | | | | |

## Costs

Costs will vary depending on the extent of the site and scope of management plan. Native grasses save money on maintenance with reduced or eliminated mowing schedules.

| Costs | L | M | H |
|---|---|---|---|
| L | ■ | ▨ | ☐ |
| M | ☐ | ☐ | ☐ |
| H | ☐ | ☐ | ☐ |

Benefits

## Benefits

High performance landscape design and management, which seeks to bring the designed landscape into a closer adherence with the region's natural systems, provides a high level of benefit. A well-designed and implemented landscape management plan results in water conservation, soil improvement, the use of less intensive practices to manage plants, and the preservation, enhancement or creation of habitat.

Landscape management, including natural lawn care practices, can help make the school grounds healthier for students and staff, protect beneficial soil organisms, and protect the environment through reduced use of water, pesticides, fertilizers, and pollution-producing mowers and maintenance equipment.

## Design Tools

To identify high performance landscape and site planning strategies, consider consulting with a landscape professional who has expertise in ecological approaches to vegetation management.

## Design Details

### Understanding the Ecological Approach

Every site has an ecological dynamism that involves all the physical elements of the landscape. A high performance approach to landscape design and management should be guided by four basic principles that respect this dynamism: resource conservation, diversity, connectivity and sustainability.

- **Resource conservation.** Identify, use and recycle available natural and physical resources that do not degrade the ecosystem.
- **Diversity.** Maintain a healthy natural system that gives primary consideration to habitat, species and genetic diversity.
- **Connectivity.** Maintain networks of natural resources and interconnecting habitats to maximize healthy ecological functions.
- **Sustainability.** Protect, restore and manage resources to maintain a healthy ecosystem in perpetuity.

In order to apply these principles to caring for a landscape, it's important to understand the difference between landscape *maintenance* and landscape *management*. Maintaining a landscape implies that there is a state to which the landscape is returned periodically, often by a maintenance crew. This static vision belies the natural dynamism of the landscape. When we seek to simply maintain, we work against the dynamic tendencies of nature, often at great expense in terms of time, energy and money.

Management, on the other hand, acknowledges dynamism, or constant change. To manage a landscape is to work with the prevailing natural tendencies, including the basic tendency of nature to change. Management informed by ecological principles does not try to return the landscape time and time again to a single, static state. Management—as opposed to maintenance—recognizes and takes advantage of the interconnection and dynamic qualities of landscape elements such as water, soil and pests.

### Establishing Landscape Management Zones

A high performance design should divide a landscape into management zones based on each zone's differing design intents and maintenance requirements. In general, there are three landscape management zones:

- Ornamental Zone: The more traditional landscape areas next to buildings, parking areas, streets and other public use facilities. This zone creates strong identity and focus for the schools. The landscape in this zone is typically designed to be organized, attractive and lush. This zone requires the highest level of management to maintain a visually pleasing and healthy appearance.
- Natural or Native Zone: Existing natural areas on or adjacent to the site that are to be preserved, enhanced or expanded.

- Buffer Zone: The interface areas between the other two zones. The management goal is to provide a visually pleasing landscape that bridges the ornamental zone and the native or more natural areas.

### Key Elements of a Landscape Management Plan

A landscape management plan needs to take into account three different functions: management of the vegetation, including lawn care; management of the site's infrastructure; and management of those responsible for its care. A landscape management plan should contain the following components:

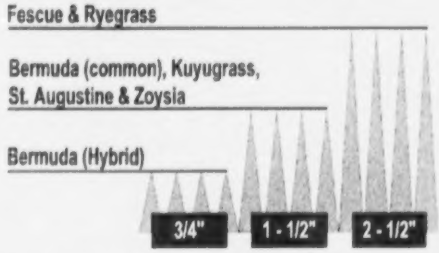
- Management vs. Maintenance: Briefly discuss the basis of an ecological approach, the concept of maintenance vs. management and the principles of ecosystem-based management.
- Vegetation Types and Locations: Discuss the concept of vegetation types, including diversity of vegetation. Also describe the landscape management zones, and list and describe the types of vegetation to be included in each zone. Provide standards that describe the desired condition of each vegetation type. Vegetation types include trees (young, street, native, ornamental, naturalized, riparian); shrubs (ornamental, naturalized, riparian, native); perennials; vegetables; meadow; lawn; groundcover; vines; and weeds and undesirable plants.
- Infrastructure Standards: Discuss standards for infrastructure care to achieve the desired condition.
- Designating Responsibility. Discuss who is responsible for each aspect of the landscape management, and delineate responsibility on a site map.
- Sustaining the Landscape: Describe the general tasks necessary to implement the landscape management specifications, including a yearly calendar of tasks as well as monthly task checklists to monitor the work and the health of the landscape.

### Natural Lawn Care

Lawns are typically the most intensively managed type of vegetation on a school site. A high performance approach to lawn care starts with considering where to have lawns at the site. Lawn can be divided into different zones based on how it will be used and how it needs to be cared for. Typically there are three standards of care to consider:

- High Intensity: Requires uniform species composition, high irrigation demands, high synthetic fertilizer use, regular pesticide and herbicide use. Primarily concerned with having uniform green grass year round with no weed, pest or soil organisms.
- Medium Intensity: Allows for more diverse species composition, less demanding irrigation, moderate organic fertilizer use, integrated pest management approach. Green is important but not essential year round. Building soil structure over time is an important goal.
- Low Intensity: Diverse species composition and/or sparse coverage is tolerable. Alternatives to lawn are considered, with other vegetation taking precedence over lawn.

**Suggested Mowing Heights**



*Grass recycling is a simple and natural approach to lawn care. Clippings are left on the lawn after mowing to decompose quickly, releasing valuable nutrients back into the soil. Proper mowing, watering and fertilizing of a lawn results in moderate turf growth, yet still produces a healthy green lawn. Illustration reprinted with permission from Los Angeles County Department of Public Works. http://www.smartgardening.com/Grass_Recycling.htm*

Plants depend on soil organisms to recycle nutrients, protect them from disease, and build loose fertile soil. Over-use of soluble fertilizers and pesticides can disrupt this ecosystem and contribute to landscape and lawn problems like thatch buildup and soil compaction. Ecological approaches to landscape management and natural lawn care practices can help make lawns healthier for our students and staff, protect beneficial soil organisms, and protect the environment.

A natural approach to lawn care produces lawns that stay healthy and are easier on the environment. Strategies include soil preparation/amendment, choosing groundcovers or no-mow lawn varieties; minimizing turf areas; "grass cycling" (leaving clippings to decompose quickly, releasing valuable nutrients back into the soil); mowing at the proper height, minimal use of pesticides; applying smaller amounts of fertilizers at regular intervals; appropriate watering; and accepting an appropriate threshold for some weeds.

## Operation and Maintenance Issues

Consider a variety of alternatives to traditional school staff for maintenance. For example, Conservation Corps or job training programs for restoration and habitat areas.

Landscape management is a different approach from conventional landscape maintenance. Planning, education, and training are key to a program's success. Each school district should develop and implement a written landscape management policy and program.

## Commissioning

None.

## Example(s)

*Profiles: A Special Report on Grounds Care.* A report of grounds maintenance challenges at Georgetown University, Washington, DC, the University of Texas Southwestern Medical Center in Dallas, and the Orange County Public School District in Orlando, Florida. Online at http://www.facilitiesnet.com/fn/NS/NS3m9li.html.

*People's Park Landscape Management: Vegetation and Infrastructure Program.* A program developed for the University of California, City of Berkeley and the Park/Community Advisory Group. This program uses an ecological approach to the renovation and care of the landscape. Information available from Wolfe Mason Associates at http://www.wolfemason.com.

## References/Additional Information.

California Department of Water Resources. 1416 - 9th Street, Room 1104-1, Sacramento, CA 95814. Tel: (916) 653-6192. Fax (916) 653-4684. Web site: http://wwwdwr.water.ca.gov.

*Clean Air Lawn Care,* South Coast Air Quality Management District. Available online at http://www.aqmd.gov/monthly/garden.html.

Cook, Tom and Roy L. Goss. *Construction and Maintenance of Natural Grass Athletic Fields.* Washington State University Cooperative Extension, Publication PNW0240. This bulletin provides the basis for development and maintenance of high quality fields for different purposes under different conditions. It is well illustrated with line drawings and color photographs plus data tables specific to different areas of the Pacific Northwest. Explains construction, establishment, drainage, irrigation, maintenance, and some troubleshooting. Rev. 1992. 28 pages. $2.25. To order call (800) 723-1763.

Craul, Phillip J. 1002. *Urban Soil in Landscape Design.* John Wiley & Sons, Inc.

Hunter, Charles D. 1997. *Suppliers of Beneficial Organisms in North America.* California Environmental Protection Agency, Department of Pesticide Regulation, Environmental Monitoring and Pest Management Branch.

*The Natural Approach to Lawn Care,* Los Angeles County Department of Public Works. Available online at http://www.smartgardening.com/grassrecycling.htm.

Olkowski, William et al. 1991. *Common Sense Pest Control.* The Taunton Press.

# Guideline SP5: Impervious Surfaces

**Recommendation**

Minimize impervious surface areas to reduce stormwater runoff. Use materials-efficient products for installed pervious and impervious surfaces.

**Description**

Impervious areas, such as roofs, driveways, sidewalks, and streets, increase stormwater runoff by preventing the infiltration of surface water into the ground. This increased stormwater runoff results in increased erosion, higher flow rates, higher ambient temperatures, and increased sediment in nearby waterways. Additionally, as stormwater flows over buildings, parking lots and play fields, it collects pollutants, such as oil, litter, and dirt. These waterborne pollutants often discharge directly into waterways. Conversely, pervious surfaces reduce peak stormwater runoff and treat stormwater pollutants. In addition, impervious surfaces create higher ambient temperatures on the site compared to pervious or vegetated alternatives.

Strategies to limit impervious surfaces on the building site include:

- Using pervious (or porous) pavement systems in lieu of impervious asphalt or concrete. Examples:
  - Porous asphalt, paver blocks, or large aggregate concrete for parking and high use bicycle and pedestrian areas.
  - Lattice blocks that permit grass growth for fire lanes and overflow parking.
  - Crushed stone or brick for lightly used pedestrian paths.
- Minimizing the amount of paving by designing for multiple uses. Uses can include access, parking, pathways, meeting places and game courts. Surfacing materials can vary depending on intensity of use, e.g. access roads paved and parking gravel ; turf block for emergency access; decomposed granite for secondary paths. All surfacing materials can utilize porous paving techniques.
- Retaining or substituting vegetation in lieu of hard surfaces.
- Designing to distribute runoff from impervious surfaces over large vegetated areas prior to reaching a stormwater conveyance system. This reduces the flow velocity, removes pollutants, and promotes groundwater infiltration.
- Installing a vegetated roof.
- Using natural or constructed wetlands to provide on-site retention and treatment of stormwater.

*Student and Staff Parking at Dominican University, River Forest, Illinois. Made with Gravelpave porous paving, manufactured by Invisible Structures, Inc., Aurora, CO (http://www.invisiblestructures.com). A porous base course was constructed on top of existing site soils to leave tree roots undisturbed. 15" deep concrete curbs were installed with forms to curve around tree bases. The final top 1" of rings, grid and fabric were anchored in place to receive the gravel.* Photo reprinted with permission from *Invisible Structures, Inc.*

| **Applicable Spaces** | | **Climates** | | **When to Consider** | |
|---|---|---|---|---|---|
| Classrooms | ☐ | South Coast | ■ | Programming | ■ |
| Library | ☐ | North Coast | ■ | Schematic | ■ |
| Mulit-Purpose / Cafeteria | ☐ | Central | ■ | Design Dev | ■ |
| Gym | ☐ | Mountains | ■ | Contract Docs | ☐ |
| Corridors | ☐ | Desert | ■ | Construction | ☐ |
| Administration | ☐ | | | Commissioning | ☐ |
| Toilets | ☐ | | | Operation | ☐ |
| Other | ☐ | | | | |

- Minimizing the building footprint through design. (Note: Minimizing building footprint usually means building "up" rather than "out." For schools, this may not be desirable because of conflicts with higher priority goals, such as daylighting and natural ventilation.)

Where impervious surfaces are necessary, use materials efficient materials. Examples include:

- Rubber modified asphalt or recycled concrete asphalt.
- Recycled aggregate for base coarse of new parking lots and roadways.
- Concrete made using flyash, a byproduct of coal combustion, to replace a portion of the Portland cement, a high embodied energy material.

*Note: One limitation of porous pavement is its tendency to clog if improperly maintained. Once it is clogged, it is difficult and costly to rehabilitate and often must be completely replaced. Clogging can be prevented most easily by not installing it in areas where erosion is a concern and by waiting until all other phases of construction are complete and vegetation is stabilized to install the pavement. Other concerns include the lack of expertise of pavement engineers and pavement contractors. Also, some studies indicate that porous systems have slightly higher deformation in porous pavement compared to conventional.*

### Applicability

All climates.

### Applicable Codes.

State Water Resources Control Board, Storm Water Program, PO Box 1977, 1001 "I" Street 15th Floor, Sacramento, CA 95814-1977, phone 916/341-5536 for general inquiries, 916/341-5537 for construction related issues, e-mail stormwater@dwq.swrcb.ca.gov, or Internet http://www.swrcb.ca.gov/stormwtr/index.htm.

*Vegetated Roof. Reprinted with permission from Samafil (Source: http://www.samafilus.com/GreenRoofs.htm)*

CERES (The California Environmental Resources Evaluation System), http://www.ceres.ca.gov/index.html features the LUPIN (The California Land Use Planning Network) wysiyg://16/http://ceres.ca.gov/planning/ with a broad array of data types from diverse sources, including selected but fully scanned and searchable county and city zoning ordinances.

Applicable landscaping codes.

Setting up a new concrete and asphalt recycling plant requires certain State and local permits, such as air and water, and zoning.

### Integrated Design Implications

Strategies to minimize impervious surfaces should be integrated with decisions about landscaping design, shading of the building, site, and heat rejection equipment, building orientation and design (footprint), roofing selection, stormwater management, parking lot and paving design, building layout, vegetated roof design, and parking lot design. Where impervious surfaces are installed, "whitetopping" (applying a layer of concrete over an asphalt base) can mitigate the local "heat island" effect and provide a tangible energy benefit.

## Costs

Minimizing paved areas means less paving material overall, which translates into lower initial cost.

The cost of pervious paving systems will vary depending on the system used. Porous (no fines) concrete for example may be comparable to conventional pavement. (This material requires a contractor familiar with the process, however.) Grid types, pavers, and brick systems have a cost premium. Cost is offset by its dual purpose as a storm water system. Less land is needed for this type of system, as area for detention, retention, or infiltration is not necessary.

*Berkeley, CA. This permeable surface doubles as an emergency vehicle access lane. Photo courtesy of Wolfe Mason Associates.*

## Benefits

Minimizing impervious surfaces helps preserve the hydrological and geological functions of a developed site by maximizing the area available for soils and vegetation to receive and treat surface water and facilitates groundwater recharge. The flow, velocity, and quantity of surface water is decreased overall, reducing the sediment and pollutant load on local waterways as well as the burden on municipal water management systems.

Ancillary benefits include reduced heat local heat build-up (heat islands) from the shading and cooling effects of vegetation, vegetated roofing, and whitetopping. These translate into reduced cooling loads and energy consumption. Several pervious pavement systems are manufactured with recycled content and so are also materials-efficient. Impervious paving that uses recycled concrete aggregate for base or flyash in concrete is also materials efficient.

## Design Tools

Applicable state and local stormwater and surface water management design manuals.

### Pervious Paving

As if this writing, there are no California guidelines or specifications for porous pavement. Guidance documents used in Washington State include:

*Interim Guidelines for the Construction of Portland Cement Pervious Pavement or "No Fines" Concrete*, a working document of the Washington State Aggregates and Concrete Association, soon to be updated. Contact the California Cement Promotion Council for more information.

*BMP T3.40, Porous Pavement*, from the *Final Draft, Stormwater Management Manual for Western Washington, Volume V, Runoff Treatment BMPs*. Washington State Department of Ecology, Water Division. August 1999, revised August 2000. This Final Draft can be downloaded at http://www.ecy.wa.gov/biblio/9915.html or call 360-407-6614.

### Recycled Concrete Asphalt for Base

Many local jurisdictions use California Department of Transportation (Caltrans) Standard Specifications. In Southern California, the Greenbook is commonly used for road projects. Where recycled aggregate is allowed, it must also, of course, meet the same grading and quality specifications as virgin aggregate.

Caltrans Standard Specifications, July 1995, covers aggregate base and aggregate subbase in Sections 25 and 26. These sections do not mention recycled aggregate. However, Caltrans SSPs do allow "reclaimed asphalt concrete, Portland cement concrete, lean concrete base, cement treated base," or "glass" in Class 2 and 3 aggregate base, and also in Class 1, 2, and 3 aggregate subbases.

The Greenbook is a public works specification book commonly used in the Los Angeles area. The Greenbook includes standardized specifications for crushed concrete and asphalt in three of its four aggregate base categories in Section 200-2, "Untreated Base Materials:"

- *Crushed Aggregate Base (CAB)* does NOT include recycled aggregate. CAB may sometimes be specified where recycled base (CMB or PMB) would also meet requirements.
- *Crushed Miscellaneous Base (CMB)* allows recycled aggregate. The *Greenbook* states that CMB "shall consist of broken and crushed AC or PCC and may contain crushed aggregate base or other rock."
- *Processed Miscellaneous Base (PMB)* also allows recycled aggregate. The *Greenbook* states that PMB "shall consist of broken or crushed AC, PCC, railroad ballast, glass, crushed rock, rock dust, or natural material."
- *Select Subbase* is the *Greenbook*'s only aggregate subbase category. It allows recycled aggregate.

#### Whitetopping

American Concrete Paving Association, *Whitetopping, State of the Practice*. Publication EB210P. This engineering bulletin covers of all aspects of concrete overlays on existing asphalt pavement. Its five chapters include: Introduction (Uses and Benefits), History and Performance, Design Practices (conventional whitetopping), Construction Practices, and Ultra-Thin Whitetopping (UTW). The last chapter presents the interim procedure for determining the load-carrying capacity of UTW based on research and performance surveys. 1998. $25.00. Order from the ACPA, http://www.pavement.com/.

### Design Details

"Effective" surfaces are those, pervious or impervious, that are connected via sheet flow (shallow or concentrated surface flow) or discrete conveyance (such as drainage ditch) to a drainage system. "Effective impervious surface" is a measure of the performance of the lot with respect to stormwater flows, which provides a way of monitoring impact due to construction. Methods to minimize runoff can be expressed: (1) prescriptively, such as using pervious surfaces or (2) performance-based, such as providing zero effective impervious surface (no net increase in run-off). Specific strategies will depend upon the specific site and local requirements.

Where impervious pavement must be used, specify the use of recycled asphalt, concrete manufactured with flyash for paving, and/or rubberized asphalt pavement. In hot climates, look for opportunities to "whitetop" asphalt surfaces with heat-reflecting white concrete.

For concrete work, use reusable steel forms, expansion joint filler with recycled content, and least toxic release methods.

When using porous paving or on-site bio-filtration swales, it is critical that subbase soils are tested so that designs are sufficient to process the stormwater flow.

Utilize surface stormwater flow wherever possible. Introduce oil/water separators at catch basins.

Note that design considerations should assume a minor loss in porosity in the first 4 to 6 years.

Avoid compaction of site soils in adjacent areas during construction to retain and infiltration and water holding capacity of existing soils.

### Operation and Maintenance Issues

For bio-swales and constructed wetlands, the design intent is to create a self-sustaining system which requires little maintenance. Monitoring and maintenance as the landscape matures provide educational opportunities. As bio-swales and constructed wetlands provide wildlife habitat, mowing and thinning plants should be minimal unless soils testing shows that impurities from runoff are high. In that case, mowing and thinning will aid in removal of toxins which may accumulate in the vegetation.

In parking areas, prune plants as needed to maintain sight lines and the desired aesthetic. If storm drains are used, clear as needed to prevent blockages. Avoid soil compaction in vegetated areas.

For porous asphalt and concrete, vacuum with a hydrovac to maintain or restore porosity by removing sediment from the paving surface. If areas become deformed by traffic, drill compacted areas to restore porosity. Keep underdrains, overflow drains and edge drains clear.

Grassed paving systems need to be mowed. Tall grasses create a less permeable surface. If this type of system is perceived as unmaintained, it may discourage potential users. The durability of the system depends on soil type and climate, however maintenance is decreased with the use of appropriate goundcover plants in lieu of lawn. Some groundcovers can take foot traffic but lawn in turf block or grids is best used where there is auto traffic.

Unit pavers on a permeable subgrade settle after the initial installation, and therefore require that a joint-filler material be swept in. Permeability decreases over time as the joints become compacted.

The systems mentioned above are conducive to "spot fixes", should replacement of small areas be required due to damage. It should also be noted that maintenance is reduced where snow removal is significant, as snow melts faster on permeable surfaces.

Longevity of the system depends on the type of system used, the amount of use it receives, and the appropriate match of system to site.

### Commissioning

N/A

### Example(s)

Ross Middle School, Ross, CA (Marin County)—Most rain leaders empty into landscaped areas: this allows percolation back to water table, reduces peak storm flows and flooding, and filters pollutants out of stormwater; Site design includes pervious surfaces where possible.

### References/Additional Information

Richman, T. et al. 1997. *Start at the Source: Residential Site Planning and Design Guidelines: Manual for Stormwater Quality Protection.* Bay Area Stormwater Management Agencies San Francisco. Brief, information-dense design guide to stormwater runoff reduction and treatment, oriented toward biological and landscaping methods. Many illustrations and diagrams.

State Water Resources Control Board, Water Recycling Programs, PO Box 1977, 1001 "I" Street 15th Floor, Sacramento, CA 95814-1977, phone 916/341-5536 for general inquiries, 916/341-5537 for construction related issues, email stormwater@dwq.swrcb.ca.gov, web site http://www.swrcb.ca.gov/stormwtr/index.html.

*Stormwater Management For Construction Activities: Developing Pollution Prevention Plans And Best Management Practices: Summary Guidance.* EPA#833-R-92-001, October 1992, EPA Office of Wastewater Management, 401 M St. SW, Mail Code EN-336, Washington DC, 20460. 800-245-6510, 202-260-7786 or www.epa.gov/owm/sw/construction/.

*Stormwater and Urban Runoff Seminars—Guide for Builders and Developers,* NAHB, Edited by Susan Asmus, Washington DC, 800-368-5242 x538 or www.nahb.com.

International Erosion Control Association (IECA). 800-455-4322 or http://www.ieca.org. Provides technical assistance and an annual Erosion Control Products and Services Directory. IECA's Western Chapter addresses issues that are unique to the Western U.S.

U.S. EPA. February 1993. *Natural Wetlands and Urban Stormwater: Potential Impacts and Management.* EPA843-R-001. Office of Wetlands, Oceans and Watersheds, Washington, DC

Stockdale, E.C. 1991. *Freshwater Wetlands, Urban Stormwater, and Nonpoint Pollution Control: A Literature Review and Annotated Bibliography.* 2nd Ed. WA Dept. of Ecology, Olympia, WA

Strecker, E.W., J.M. Kersnar, E.D. Driscoll & R.R. Horner. April 1992. *The Use of Wetlands for Controlling Stormwater Pollution.* The Terrene Inst., Washington, DC

California. 1993. *California Stormwater Best Management Practice Handbook: Construction Activities.* Prepared for Stormwater Quality Task Force. Camp Dresser and McKee, Larry Walker Associates, Uribe and Associates and Resources Planning Associates. 183p.

Integrated Waste Management Board (California) Database of Recycled-Content Providers: http://www.ciwmb.ca.gov/rcp.

*Designing with Vision: A Technical Manual for Material Choices in Sustainable Construction.* Revised July 2000. A publication of the California Integrated Waste Management Board. See Chapter 8, "Strategies to Reuse Materials and Reduce Material Use in Construction," Appendix E sample specifications for: Section 02145, Erosion Control; Section 02230, Base Course; Section 02513, Asphaltic Concrete Paving. *Designing with Vision* can be downloaded in four parts from http://www.ciwmb.ca.gov/GreenBuilding. Chapter 8 is in Part D.

Integrated Waste Management Board (California) Database of Recycled-Content Providers: http://www.ciwmb.ca.gov/rcp. (for sources of recycled content aggregate (RCA))

*Recycled Aggregate,* A CIWMB Fact Sheet, CIWMB publication #431-95-052. Also available to download from http://www.ciwmb.ca.gov/publications/condemo/43195052.doc.

Southern California Rock Products Association | Southern California Ready Mixed Concrete Association, http://www.scrpa.com/.

California Cement Promotion Council, Dave Holman, phone (925) 838-0701 or dholman@best.com.

# Guideline SP6: Drought Tolerant and Pest-Resistant Plants

## Recommendation

Preserve existing vegetation, especially groups of plants or significant specimens wherever possible; design for plant survival since many landscape areas in schools can be destroyed by intensive use; design landscapes with a minimal water-use budget. This is commonly achieved with the use of native, drought-tolerant vegetation and the use of low flow irrigation systems.

*Davis, CA. These groupings of native, quick growing perennial grasses require little irrigation and thrive in high use areas. Photo courtesy of Wolfe Mason Associates.*

| **Applicable Spaces** | | **Climates** | | **When to Consider** | |
|---|---|---|---|---|---|
| Classrooms | ☐ | South Coast | ■ | Programming | ☐ |
| Library | ☐ | North Coast | ■ | Schematic | ☐ |
| Mulit-Purpose / Cafeteria | ☐ | Central | ■ | Design Dev | ■ |
| Gym | ☐ | Mountains | ■ | Contract Docs | ■ |
| Corridors | ☐ | Desert | ■ | Construction | ■ |
| Administration | ☐ | | | Commissioning | ☐ |
| Toilets | ☐ | | | Operation | ■ |
| Other | ☐ | | | | |

## Description

Existing vegetation is the easiest and most cost effective way to landscape the site. It also provides historical connection to the surrounding neighborhood. Plant survival can be increased by using tough plants that can take foot traffic such as plants grown from corms or bulbs. (Good examples include *Dietes vegeta, Acanthus mollis, Phorium sp.*, and many of the grasses, reeds and sedges.) These tough plants should anchor corners and edges of planted areas. Also using raised beds, curbs and temporary but artistic barriers can help protect plants into maturity. Preparing designs and management programs that layer plant types, use a mixture of sizes at initial plantings and plan for plant succession will also help.

Native vegetation is adapted to regional climate conditions. They are easy to establish, are drought tolerant (require little or no irrigation once established), and are naturally disease-resistant and pest-resistant. Planting for minimal water use is also referred to as "xeriscaping" or "drought-tolerant" landscaping.

## Applicability

This guideline applies to all climates, but is especially important in the Central Valley, southern coastal, and desert climates.

## Applicable Codes.

Model Water Efficient Landscape Ordinance, Division 2, Title 23, California Code of Regulations, Chapter 2.7, Sections 490 through 495 (http://wwwdpla.water.ca.gov/cgi-bin/urban/conservation/landscape/ordinance/index).

## Integrated Design Implications

Drought tolerant landscaping should be integrated/coordinated with Guideline SP9: *Landscaping Soil, Amendments and Mulch;* Guideline SP4: *Landscape Design & Management: Vegetation, Infrastructure and Natural Lawn Care,* Guideline SP2: *Landscaping to Provide Shade to Buildings and Paved Areas,* Guideline SP7: *Location of HVAC Equipment,* and Guideline SP13: *Integrated Weed, Disease and Pest Management.* All landscape planning should also take into account irrigation system parameters to assist in the goal of maximum efficiency. See Guideline SP10: *Water-efficient Irrigation Systems.*

## Costs

Costs are competitive with or only slightly higher than conventional landscape design. Additional cost benefit if reusing existing vegetation.

Costs

|  | L | M | H |
|---|---|---|---|
| L | ■ | ▨ |  |
| M |  |  |  |
| H |  |  |  |

Benefits

## Benefits

The use of drought tolerant, native species conserves water (thereby reducing water costs), provides lots of attractive planting options, presents minimal disease and pest problems, thrives with little fertilization, requires low pruning and maintenance, provides wildlife habitat, and saves valuable landfill space. If retaining native vegetation in a landscape (rather than removing them and then replanting), you also benefit from excellent erosion, sediment, dust, and pollution control.

## Design Tools

Landscaping for minimal irrigation also requires careful planning of plant groupings, the "right plant, right place" concept, soil considerations, and other landscape design practices. The use of landscape professional with expertise in drought tolerant vegetation is recommended.

Irrigation Water Needs of Landscape Plants in California,
*http://wwwdpla.water.ca.gov/urban/conservation/landscape/wucols/index.html*

Landscape Auditors certified by the Irrigation Association (703)536-7080), link: http://www.irrigation.org/

## Design Details

Add language into construction specs to protect existing plants, especially trees and root systems.

Soils are often disturbed during construction activities, and native vegetation may not thrive in degraded soils. Unless soil amendments are used to restore disturbed soil, it may be more appropriate to use water-efficient, non-native vegetation. See Guideline SP9 for using soil amendments.

Clearly define planting zones by intended use, e. g. lawns for play; tree groves for shade and habitat; shrub masses for buffering and screening; etc.

Introduce plants to increase habitat, e. g. butterflies and hummingbirds.

Create a diversity of landscape areas, e. g. ponds, meadows and groves; community gardens; vines and perennials, etc.

## Operation and Maintenance Issues

Native, drought tolerant plants are usually hardier and more pest-resistant, requiring less fertilizer and pesticide use. Use organic, slow release fertilizers and integrated pest management for pest control. See Guideline SP13 for integrated pest management.

Recommend that landscape contractor specify in maintenance contract that new landscaped areas be maintained for a 2-3 year plant establishment period. Monthly findings on plant establishment should be reported to owner.

## Commissioning

None

## Example(s)

Peterson Nature Area, Peterson Middle School, Sunnyvale, California.
http://www.peterson.scu.k12.ca.us/~bosborne. Contact: Bryan Osborrne, Peterson Middle School, bryosborne@mail.telis.org, Santa Clara Unified School District, 720-8540.

Ross Middle School, Ross, CA (Marin County)—Habitat Garden includes native plants to minimize water use and educate students; Building was designed around three large existing oaks, extensive protection measures were taken.

### References/Additional Information

California Department of Water Resources. 1416 - 9th Street, Room 1104-1, Sacramento, CA 95814, Phone (916) 653-6192, fax (916) 653-4684, http://wwwdwr.water.ca.gov.

California Landscape Contractors Association (CLCA). Phone (916) 448-2522, fax (916) 446-7692, or web site (with an on-line contractor search) at http://www.clca.org/index.html.

California Native Plants Society, http://www.cnps.org/index.htm.

City of Fort Collins. (March 1999). *Xeriscape: a New Kind of Landscaping.* http://www.ci.fort-collins.co.us/utilities/water/conserv/xeriscap.htm. A summary of environmentally responsive landscaping resources, including a list of very low, low and moderate water consumption.

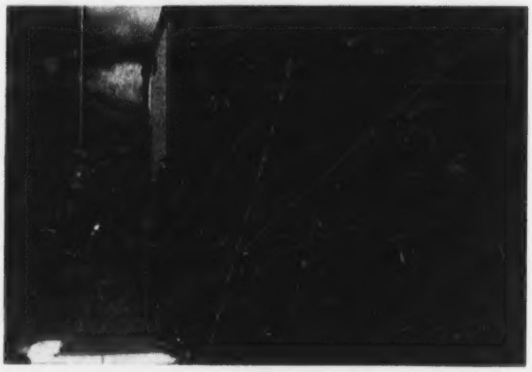
City of Santa Barbara. (March 1999). *Water Conservation Program: Landscaping.* http://ci.santa-barbara.ca.us/departments/public_works/water_resources. An excellent and visual orientation to water-conserving landscaping on the Southern California coast.

*Managing a Waste-Efficient Landscape,* and on-line publication of the California Integrated Waste Management Board, URL http://www.ciwmb.ca.gov/organics/Landscaping/KeepGreen/Manage.htm.

Marsh, W. M. 1991. *Landscape Planning: Environmental Applications.* John Wiley & Sons, New York. A definitive reference for landscape architects, planners and designers on the definition and application of environmental design principles to landscape and site planning.

WaterWiser—a program of the American Water Works Association operated in cooperation with the U.S. Bureau of Reclamation. The website www.waterwiser.org provides information and resources including links for all aspects of outdoor and indoor water conservation, recycled water collection and reuse, irrigation, landscaping, and efficient fixtures and appliances. AWWA number is 202-628-8303.

# Guideline SP7: Location of HVAC Equipment



*Berkeley, CA. Landscaping outside of Willard Middle School was created without a landscaping budget: all vegetation was grown by students, teachers, and volunteers. HVAC equipment for gymnasium is located behind landscaping for shade and to obstruct it's view from the street. Photo courtesy of Wolfe Mason Associates.*

| Applicable Spaces | | Climates | | When to Consider | |
|---|---|---|---|---|---|
| Classrooms | ☐ | South Coast | ■ | Programming | ■ |
| Library | ☐ | North Coast | ■ | Schematic | ■ |
| Mulit-Purpose / Cafeteria | ☐ | Central | ■ | Design Dev | ■ |
| Gym | ☐ | Mountains | ■ | Contract Docs | ☐ |
| Corridors | ☐ | Desert | ■ | Construction | ☐ |
| Administration | ☐ | | | Commissioning | ☐ |
| Toilets | ☐ | | | Operation | ☐ |
| Other | ■ | | | | |

### Recommendation

Shade Heating, Ventilation, and Air Conditioning (HVAC) Equipment from direct sun. Locate intake ducts away from sources of pollution.

### Description

Shading HVAC equipment from direct sunlight can significantly lower the cooling demand. Locating fresh air intake ducts away from loading docks, exhaust vents, parking lots, or other sources of pollution preserves indoor air quality.

### Applicability

All climates.

### Applicable Codes

N/A

### Integrated Design Implications

HVAC location and design should be considered in conjunction with, SP1 Optimum Building Orientation, SP5 Impervious Surfaces, HVAC systems, Building Enclosure and Design.

### Costs

Costs are minimal, particularly if incorporated into overall HVAC system and landscaping design. Consult with a qualified HVAC engineer regarding opportunities for downsizing systems due to decreased system load.

| Costs | Benefits L | Benefits M | Benefits H |
|---|---|---|---|
| L | ☐ | ☐ | ■ |
| M | ☐ | ☐ | ☐ |
| H | ☐ | ☐ | ☐ |

### Benefits

Proper location of the intake ducts is essential for good indoor air quality. Shading HVAC equipment lowers demand for electricity and reduces the potential for urban heat islands.

### Design Tools

N/A

### Design Details

Locate HVAC equipment so that it is shaded from afternoon sun during the cooling season.

Plant trees so that at maturity their canopies shade the unit and the adjacent area during the entire cooling season. However, do not impede the ability of air to circulate around the unit.

### Operation and Maintenance Issues

Care must be taken to avoid contaminating HVAC equipment with leaves or other organic debris; maintenance must also avoid plantings growing too dense and preventing the proper circulation of air around the unit.

### Commissioning

N/A

### Example(s)

N/A

### References / Additional Information

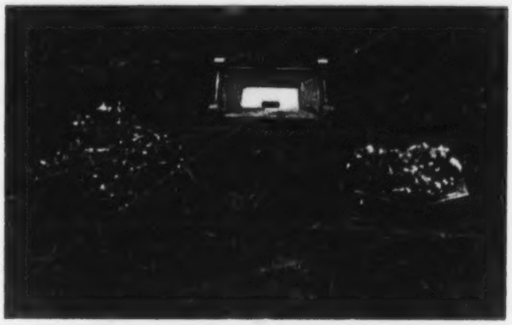
Parker, D.S. "Measured Impacts of Air Conditioner Condensor Shading." The Tenth Symposium on Improving Building Systems in Hot and Humid Climates. Fort Worth, TX, 1996. Archived at http://www.fsec.ucf.edu/~bdac/pubs/PF302/PF302.htm, 12/15/00.

Parker, J.H. "The Impact of Vegetation on Air Conditioning Consumption," Proceedings of the Workshop on Saving Energy and Reducing Atmospheric Pollution by Controlling Summer Heat Islands, Berkeley, CA, p. 45-52, 1989.

# Guideline SP8: Landscaping Accessories

## Recommendation

Use recycled content products or salvaged materials for site and landscaping accessories. Salvage materials can originate from both on and off site sources.



*Square waste receptacle and planters, The Plastic Lumber Company, Inc., Product #FP6000LID. http://www.plasticlumber.com. Reprinted with permission from The Plastic Lumber Company.*

| Applicable Spaces | | Climates | | When to Consider | |
|---|---|---|---|---|---|
| Classrooms | ☐ | South Coast | ■ | Programming | ☐ |
| Library | ☐ | North Coast | ■ | Schematic | ☐ |
| Mulit-Purpose / Cafeteria | ☐ | Central | ■ | Design Dev. | ■ |
| Gym | ☐ | Mountains | ■ | Contract Docs | ■ |
| Corridors | ☐ | Desert | ■ | Construction | ■ |
| Administration | ☐ | | | Commissioning | ☐ |
| Toilets | ☐ | | | Operation | ☐ |
| Other | ☐ | | | | |

## Description

Many site and landscaping accessories are now available that are made with post-consumer and post-industrial recycled materials. Examples include parking stops, bike racks, tree cuffs, grates, landscaping ties, planters, outdoor furniture, and posts for lighting and signs. Specific examples include:

- Synthetic surfacing for exterior sports surfaces, playgrounds, and other surfaces. Made from 84 to 98 % post-consumer rubber from used tires
- Fencing with made with recycled plastic or salvaged wood or metal.
- Running track surfaces made with 100% recycled rubber/tires.

## Applicability

All climates.

## Applicable Codes

Applicable codes for structural elements, such as benches and playground surfaces and equipment.

## Integrated Design Implications

None.

## Costs

In general, costs are comparable to conventional options, except for steel forms.

| Costs \ Benefits | L | M | H |
|---|---|---|---|
| L | ■ | | |
| M | | | |
| H | | | |

## Benefits

Use of recycled content products helps alleviate waste disposal problems, reduces energy use and consumption of natural resources during manufacturing.

## Design Tools

*Designing with Vision: A Technical Manual for Material Choices in Sustainable Construction.* Revised July 2000. A publication of the California Integrated Waste Management Board. See Chapter 8, "Strategies to Reuse Materials and Reduce Material Use in Construction," Appendix E sample specifications for Section 02507, Plastic Wheel Bumpers. *Designing with Vision* can be downloaded in four parts from http://www.ciwmb.ca.gov/GreenBuilding/. Chapter 8 is in Part D.

Also, consult the environmentally preferable product directories (see the discussion of product directories in the Introduction to the Guidelines, *Material Selection and Research*). See also product databases listed under *References/Additional Information, below.* Many manufacturers provide sample specifications.

### Design Details

Product finishes can vary. Some recycled products are not as strong as products made with virgin materials.

### Operation and Maintenance Issues

Varies with product. In some cases, maintenance needs are less. For example, plastic lumber is more durable and requires less ongoing maintenance than wood.

### Commissioning

NA

### Example(s)

Ross Middle School, Ross, CA (Marin County)—Sun shades and landscape benches are made from certified sustainably harvested Ipe or Angico. Concrete mix design replaces 50% of cement with flyash.

### References/Additional Information

Santa Barbara County Waste Management Board: Recycled Content Providers:
http://www.lessismore.org/htdocs/text_only/important_info/recycled_products.html.

Integrated Waste Management Board (California) Database of Recycled-Content Providers:
http://www.ciwmb.ca.gov/rcp.

# Guideline SP9: Landscaping Soil, Amendments and Mulch

### Recommendation

Use organic soil amendments to help restore the health of disturbed soils. Where feasible and appropriate, use soil amendments and mulch with recycled content.

### Description

The appropriate use of organic soil amendment will offset degradation in soil health due to construction activities, reduce run-off, help treat stormwater pollutants, and help ensure establishment of vegetation. Where feasible, use soil amendments from composted green waste and mulch from shredded bark which adheres better to the soil.

*Davis, CA. Mulch areas 3-4" deep prevent weed growth, protect soil, and prevent irrigation from washing it into other areas. Mulch can be walked on and used to replenish the soils of high use areas. Photo courtesy of Wolfe Mason Associates*

| Applicable Spaces | | Climates | | When to Consider | |
|---|---|---|---|---|---|
| Classrooms | ☐ | South Coast | ■ | Programming | ☐ |
| Library | ☐ | North Coast | ■ | Schematic | ■ |
| Mulit-Purpose / Cafeteria | ☐ | Central | ■ | Design Dev | ■ |
| Gym | ☐ | Mountains | ■ | Contract Docs | ▨ |
| Corridors | ☐ | Desert | ■ | Construction | ▨ |
| Administration | ☐ | | | Commissioning | ☐ |
| Toilets | ☐ | | | Operation | ■ |
| Other | ☐ | | | | |

### Applicability

All climates.

### Applicable Codes

Model Water Efficient Landscape Ordinance, Division 2, Title 23, California Code of Regulations, Chapter 2.7, Sections 490 through 495 http://wwwdpla.water.ca.gov/cgi-bin/urban/conservation/landscape/ordinance/index.

Applicable local ordinances (for example, City of Palo Alto. Landscape Water Efficiency Standards. March 15, 1993.)

### Integrated Design Implications

Soil amending should be integrated/coordinated with Guideline SP6: *Drought-tolerant and Pest-resistant Plants*, Guideline SP4: *Landscape Design & Management: Vegetation, Infrastructure and Natural Lawn Care*, Guideline SP2: *Landscaping to Provide Shade to Buildings and Paved Areas*, and Guideline SP7: *Location of HVAC Equipment*.

### Costs

Medium.

| Costs | L | M | H |
|---|---|---|---|
| L | | | |
| M | | ■ | ▨ |
| H | | | |

Benefits

### Benefits

Research at the University of Washington has shown that, compared to traditional lawn installations, landscape grown on composted-amended soils:

- Uses less water for irrigation
- Requires less fertilizer and pesticide
- Covers and "greens up" more quickly

- Has improved appearance
- Reduces stormwater run-off

### Design Tools

Appropriate use of soil amendments requires site soil testing and analysis to determine type and amount of amendment.

### Design Details

Key steps in creating and maintaining healthy soil and amendments include:

1. Minimize disturbance of existing soil.
2. Test the horticultural suitability of existing soil.
3. Strip and save suitable existing soil for re-use in landscape areas.
4. All existing soil in areas to be planted that have been degraded and compacted from building construction must be scarified before planting. In general and depending on soil type, planting soils can not be compacted more than 80%so that air and water can percolate through the soil cross section.
5. Incorporate organic soil amendments from composted green waste to help restore the health of disturbed soils.
6. Use a minimum 3-4 inch layer of mulch at all planting areas to help retain soil moisture and discourage weed growth. Some types of mulch can also take foot traffic.

Urban development often involves clearing, removing topsoil, cuts, and fills. Once the work is done, the remaining soil is often much less healthy than the original, native soil:

*Table 4 – Characteristics of Healthy vs. Disturbed Urban Soil*

| Healthy Native Soil | Disturbed Urban Soil |
|---|---|
| • Stores water and nutrients—Contains a rich, diverse makeup of organisms, organic matter, and pores. Healthy soil acts like a giant sponge, storing and slowly releasing water, oxygen, and nutrients to plants as needed.<br>• Regulates water flow—Maintains the natural water cycle by slowly discharging to streams and lakes and recharging aquifers.<br>• Neutralizes pollutants—Soil rich in organic matter contains microorganisms that can immobilize or degrade pollutants. | • Compacted—The removal of topsoil exposes subsoil that is often compacted. Heavy construction equipment can further compact soils. These dense layers resist plant root penetration and lack pores needed for adequate aeration. As a result, the soil is less able to absorb, retain, and filter (purify) groundwater.<br>• Reduced storage capacity—Because subsoil are less able to retain water, more stormwater ends up as run-off, disrupting the natural water cycle and degrading the health of nearby streams and waterways.<br>• Poorer quality—The subsoil layer generally contains less organic matter and fewer nutrients than rich topsoil. This soil is less able to immobilize or degrade pollutants. |

The result is increased erosion and stormwater run-off as well as higher flow rates, higher temperatures, and increased sediment in nearby streams. In addition, developed sites with poor soil typically require more irrigation, pesticides, and fertilizers to establish and maintain landscaping. Increased water usage as well as pesticide/fertilizer run-off causes further habitat damage.

## Operation and Maintenance Issues

Vegetation grown on amended soils establish more quickly and require less ongoing maintenance, compared to vegetation grown on un-amended, disturbed urban soil.

## Commissioning

N/A

## Example(s)

## References/Additional Information.

The California Compost Quality Council (CCQC). A collaboration of compost producers, scientists, farmers, landscape contractors, and recycling advocates formed to administer compost quality guidelines in California. The CCQC operates an independent verification program through which compost producers can assure consumers that quality claims have been verified. The California Compost Quality Council, 584 Castro Street, San Francisco, CA 94114, phone (415) 863-1048 or web site http://www.crra.com/ccqc/ccqchome.htm.

California Landscape Contractors Association (CLCA). Phone (916) 448-2522, fax (916) 446-7692, or web site (with an on-line contractor search) at http://www.clca.org/index.html.

California Organic Recycling Council (CORC). Web site: http://www.crra.com/corchome.htm

Compost and Mulch Sources List from the California Integrated Waste Management Board. Listings for Northern, Central, and Southern California. http://www.ciwmb.ca.gov/organics/SupplierList/ListCent.htm.

The Landscape Architects Technical Committee (LATC). Under the purview of the California Architects Board, the LATC was created by the California Legislature to protect the health, safety and welfare of the public by establishing standards of licensure and the enforcing of laws and regulations which govern the profession of landscape architecture. It is one of the numerous boards, bureaus, commissions, and committees within the Department of Consumer Affairs responsible for consumer protection and the regulation of licensed professions. State of California, Department of Consumer Affairs, California Architects Board, Landscape Architects Technical Committee, 400 R Street Suite 4000 Sacramento, Ca 95814, phone 916-445-4954, fax: 916-324-2333, web site http://www.latc.dca.ca.gov/index.htm.

# Guideline SP10: Water-Efficient Irrigation Systems

### Recommendation

Install drip or other low-volume, water-efficient irrigation where appropriate.

*Photo reprinted with permission from Rain Bird Sprinkler Mfg. Corp.*
*http://www.rainbird.com/rbturf/products/xeri/xeri.htm*

| Applicable Spaces | |
|---|---|
| Classrooms | ☐ |
| Library | ☐ |
| Mulit-Purpose / Cafeteria | ☐ |
| Gym | ☐ |
| Corridors | ☐ |
| Administration | ☐ |
| Toilets | ☐ |
| Other | ☐ |

| Climates | |
|---|---|
| South Coast | ■ |
| North Coast | ■ |
| Central | ■ |
| Mountains | ■ |
| Desert | ■ |

| When to Consider | |
|---|---|
| Programming | ☐ |
| Schematic | ☐ |
| Design Dev. | ■ |
| Contract Docs. | ■ |
| Construction | ■ |
| Commissioning | ☐ |
| Operation | ■ |

### Description

Supplemental irrigation accounts for most water use at schools during the summer and a significant amount during the spring and fall. Maximizing the water efficiency of irrigation systems supports healthy and attractive landscapes and sports fields.

### Applicability

All climates.

### Applicable Codes.

Model Water Efficient Landscape Ordinance, Division 2, Title 23, California Code of Regulations, Chapter 2.7, Sections 490 through 495 (http://wwwdpla.water.ca.gov/cgi-bin/urban/conservation/landscape/ordinance/index), or applicable local ordinances.

### Integrated Design Implications

Irrigation system design and installation should be closely coordinated with other landscape planning and water management activities. See SP6: *Drought-tolerant and Pest-resistant Plants*, SP9: *Landscaping Soil, Amendments and Mulch*, SP4: *Landscape Design & Management: Vegetation, Infrastructure and Natural Lawn Care*, SP13: *Integrated Weed, Disease and Pest Management*, and OM3: *Rainwater Collection Systems.* Note: The soil should be amended and blended prior to installing the irrigation systems to avoid damage to the system.

### Costs

Drip systems and micro-emitters have become very cost effective when evaluated against water restrictions and rising water costs.

| Costs | L | M | H |
|---|---|---|---|
| L | ☐ | ☐ | ■ |
| M | ☐ | ☐ | ☐ |
| H | ☐ | ☐ | ☐ |

Benefits

### Benefits

Significant reduced irrigation water consumption, conserving water and reducing utility costs. (Conventional spray heads deliver only 55 to 65 & of the water to the ground; the rest is blown away or evaporates, depending on weather conditions. In contrast, drip irrigation is up to 95 percent efficient.) Plants establish and thrive better with drip irrigation since water is delivered to the root zone, where it is needed. Water efficient irrigation systems are also *waste* efficient—water and fertilizer are used only where needed, preventing nutrient-consuming and waste-generating weed growth in other areas and reducing costs associated with managing and disposing of undesired plant growth.

### Design Tools

None.

### Design Details

- First, aim to eliminate the need for an irrigation system at all. An effective stewardship program combined with drought-tolerant plants (SP6), might eliminate the need for an in-ground system.
- Where an in-ground system is required, the design and installation should be accomplished by a certified irrigation specialist and is to conform to local Water Efficient Landscape Ordinance. The ordinances include specifics about efficient irrigation.
- Systems should be installed to avoid runoff, low-head drainage, overspray, or other similar conditions where irrigation water flows onto adjacent property, non-irrigated areas, or impervious surfaces. Consider special problems posed by irrigation on slopes, in median strips, and in narrow hydrozones. Installation should provide easy access to sprinkler heads for inspection and maintenance.
- Use irrigation zones to group plants with similar water needs close to a water source to help limit the scope and impact of an in-ground irrigation system.
- Where possible, use the minimum amount of PVC (Polyvinyl Chloride) products. PVC is highly toxic during manufacture and disposal. Unfortunately, the alternatives, such as copper, or clay piping tend to be more expensive. If substitution for virgin PVC is not an option, the system should be designed so as to use the minimum length of piping possible.
- Consider using irrigation systems made with recycled content plastic, tire-derived rubber, and other recycled-content materials. See the CIWMB Recycled Content Product Database at http://www.ciwmb.ca.gov/rcp/.
- Preserve established vegetation to minimize irrigation needs. Avoid killing existing vegetation with too much water from new irrigation systems.

### Operation and Maintenance Issues

Requires regular monitoring to ensure system is operating properly. Develop a monthly schedule to visually inspect and monitor irrigation system(s) performance during irrigation season. Performance evaluation is to be based upon and compared to original design intent, irrigation audit report, and water budget goals.

### Commissioning

Work with the commissioning agent and certified irrigation auditor to ensure compliance with the design documents. In addition to checking for proper irrigation equipment and installation, check system for adherence to specified performance criteria and operation parameters as designed. Verify that maintenance personnel are trained and capable of ongoing programming of and adjustments to the irrigation system.

### Example(s)

Cook, Tom. *What Went Wrong? Problems with Athletic Fields* (A Pacific Northwest Perspective).

Hawn, Joellyn. "Process Changes to Improve Commercial Landscape Viability." *New England Real Estate Journal*, May 31-June 6, 1996.

### References/Additional Information

California Department of Water Resources. 1416 - 9th Street, Room 1104-1, Sacramento, CA 95814, Phone (916) 653-6192, fax (916) 653-4684, http://wwwdwr.water.ca.gov.

Costello, L. R. and K. S. Jones, *A Guide to Irrigation Water Needs of Landscape Plants in California*, University Of California Cooperative Extension. 1999 Edition. On-line at URL http://wwwdpla.water.ca.gov/urban/conservation/landscape/wucols/index.html.

*Drip Irrigation for Every Landscape and All Climates*, by Robert Kourik, Metamorphic Press, PO Box 1841, Santa Rosa, CA 95402.

Irrigation Association, various publications, including *Common Obstacles to Irrigation Efficiency* and *Drip Irrigation Technology*. Available online at http://www.igin.com/irrigation/irrigation.html

Kourik, R. 1992. *Drip Irrigation for Every Landscape and All Climates.* _Metamorphic Press, Santa Rosa. One of the most thorough books available on design and construction of drip irrigation systems.

*Landscape Water Management Principles*, Version 1.01. Cal Poly ITRC, San Luis Obispo, CA, 1994.

Netdim Irrigation Inc. 1998. *Techline Design Manual.*_Netafim Irrigation, Inc. Landscape Division. Fresno, CA. A technical primer for designing drip irrigation systems.

*WaterWiser* is a program of the American Water Works Association operated in cooperation with the U.S. Bureau of Reclamation. The website www.waterwiser.org provides information and resources including links for all aspects of outdoor and indoor water conservation, recycled water collection and reuse, irrigation, landscaping, and efficient fixtures and appliances. AWWA number is 202-628-8303.

# Guideline SP11: Stormwater Management and Drainage Materials

**Recommendation**

Manage stormwater with systems that slow water velocity, maximize its use for irrigation, and filter pollutants. Use materials efficient options for on-site drainage systems.

**Description**

Stormwater management is vital to the safety and ecological health of a school site. Site planning and design should strive to balance water on the site and make effective use of the water for water supply and irrigation.

Water should always be absorbed and captured with the remainder moved slowly across the site into natural features wherever possible. Trying to move water quickly to gutters, downspouts, catch basins and pipes increases water quantity and velocity requiring the design of large and expensive drainage infrastructure. Options for efficient drainage materials include: for fill—recycled concrete aggregate (RCA), crushed concrete, and glass; for pipes—EPS with recycled content.

*Berkeley, CA. A boulder bridge spans a surface swale in the edible garden at King Middle School. The swale allows water to percolate back into the soil and eliminates the need for pipes. Students grow produce and sell it at local markets to raise funds for schools groups. Photo courtesy of Wolfe Mason Associates.*

| Applicable Spaces | | Climates | | When to Consider | |
|---|---|---|---|---|---|
| Classrooms | ☐ | South Coast | ■ | Programming | ☐ |
| Library | ☐ | North Coast | ■ | Schematic | ☐ |
| Mulit-Purpose / Cafeteria | ☐ | Central | ■ | Design Dev | ■ |
| Gym | ☐ | Mountains | ■ | Contract Docs | ■ |
| Corridors | ☐ | Desert | ■ | Construction | ■ |
| Administration | ☐ | | | Commissioning | ☐ |
| Toilets | ☐ | | | Operation | ■ |
| Other | ☐ | | | | |

**Applicability.**

All climates.

**Applicable Codes**

State Water Resources Control Board, Storm Water Program, PO Box 1977, 1001 "I" Street 15th Floor, Sacramento, CA 95814-1977, phone 916/341-5536 for general inquiries, 916/341-5537 for construction related issues, e-mail stormwater@dwq.swrcb.ca.gov, or Internet http://www.swrcb.ca.gov/stormwtr/index.htm.

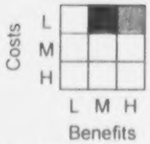
CERES (The California Environmental Resources Evaluation System), http://www.ceres.ca.gov/index.html features the LUPIN (The California Land Use Planning Network) wysiyg://16/http://ceres.ca.gov/planning/ with a broad array of data types from diverse sources, including selected but fully scanned and searchable county and city zoning ordinances.

Applicable specifications for fill and drainage materials.

**Integrated Design Implications**

Building design (especially roofs), site grading, erosion control and bank stabilization.

## Costs



On site capture, absorption, and slowing of surface runoff usually has lower first cost and ongoing maintenance expense. Drainage material costs are comparable or less than conventional materials. For example, recycled aggregate base is less expensive than virgin aggregate in the Los Angeles area. There also may be an economic advantage to crushing concrete and asphalt demolition debris on site, where the material can be used on site as base or sub-base. The economy of on-site crushing depends on several variables including the amount of rubble stockpiled, the capacity of the crushing equipment available (tons per hour), local tipping fees for the inert materials, the haul distance to local inert landfills, and the total cost of importing virgin or recycled aggregate base to the construction site.

## Benefits

Capturing and absorbing stormwater is good water conservation. It also can improve the health of on site soils, vegetation and habitat areas. Use of recycled content products helps alleviate waste disposal problems, reduces energy use and consumption of natural resources during manufacturing.

## Design Tools.

N/A

## Design Details

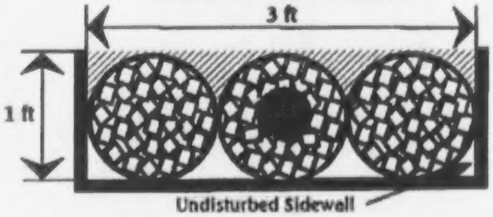
Stormwater management should begin with capture in cisterns, ponds, etc. and absorption into groundwater aquifers, landscape areas, etc. Excess percolated water from green roofs and pervious paving should be filtered through vegetated areas or filters.

Any remaining water to runoff should be slowed down and spread slowly over the entire surface of roofs and paved areas before entering bioswales and surface runoff channels such as brooks and creeks.

If pipes and catch basins are used, use perforated pipe and filters wherever possible.

Natural boulders can be effective as energy dissipaters or as checkdams creating riffles and pools in the channels.

**E-Z Drain 2012-3 Conventional Trench**



*The basic unit of E-Z Drain is a 10 foot length of 4-inch perforated corrugated plastic pipe surrounded by EPS aggregate held in place by a cylindrical shaped polyethylene netting either 10 or 12 inches in diameter. Made from 60% to 100% recycled EPS. Illustration reprinted with permission from E-Z Drain Company. www.ezdrain.com*

Use green roofs and bioswales at buildings. Use site grading with bioengineered banks and channels, energy dissipaters and check dams. Broken and excess masonry and concrete are good inert fill materials under sidewalks and driveways. If space permits, excess concrete can be crushed on site and used as aggregate on another part of the site or on another construction job.

## Operation and Maintenance Issues

Most traditional maintenance programs at schools are limited trash pickup and 'mow and blow' cleanup. Local conservation corps, youth job training programs, community and master gardeners, and neighborhood groups are good sources to help augment the school maintenance staff. They can help nurture a variety of landscapes especially natural waterways and riparian corridors, ponds, meadows, gardens native planting beds.

## Commissioning

N/A

### Example(s)

Blackberry Creek Restoration at Thousand Oaks School, Berkeley , CA. Designed by Wolfe Mason Associates with the Waterways Restoration Institute, Oakland and Berkeley, CA.

Kids in Creeks Program for School Teachers. Aquatic Outreach Institute, Richmond, CA.

### References/Additional Information

*Designing with Vision: A Technical Manual for Material Choices in Sustainable Construction.* Revised July 2000. A publication of the California Integrated Waste Management Board. See Chapter 8, "Strategies to Reuse Materials and Reduce Material Use in Construction," Appendix E sample specifications for: Section 02045, Rock Crushing Operations. *Designing with Vision* can be downloaded in four parts from http://www.ciwmb.ca.gov/GreenBuilding/. Chapter 8 is in Part D.

Integrated Waste Management Board (California) Database of Recycled-Content Providers: http://www.ciwmb.ca.gov/rcp. (for sources of recycled content aggregate (RCA))

*Recycled Aggregate* Fact Sheet, CIWMB publication #431-95-052. Also available to download from: http://www.ciwmb.ca.gov/publications/condemo/43195052.doc.

*Stream Corridor Restoration: Principles, Processes and Practices* developed by 14 Federal Agencies. Available at http://www.usda.gov/streamrestoration/

# Guideline SP12: Reclaimed Water for Irrigation

## Recommendation

Use reclaimed water for irrigation, where appropriate. More detailed information is described in the Other Systems Chapter of this Manual. See Guidelines OS3 (Rainwater Collection Systems) and OS4 (Gray Water Systems)

## Description

Reclaimed water can be non-potable water supplied by the water company, graywater, water collected from the stormwater system, or rainwater collected from the roof, ground, or impervious surfaces.

## Applicability

Should be considered in all climates, but the local pattern of rainfall may make the guideline unfeasible because of resulting storage tank requirements.

*Windsor, CA. The grounds at Windsor High School are irrigated with reclaimed water from the local water municipality. The municipality waived the hookup costs, and the school saves money every month by not using potable water for irrigation. Photo courtesy of Quattrocchi / Kwok Architects*

| Applicable Spaces | | Climates | | When to Consider | |
|---|---|---|---|---|---|
| Classrooms | ☐ | South Coast | ■ | Programming | ☐ |
| Library | ☐ | North Coast | ■ | Schematic | ☐ |
| Mulit-Purpose / Cafeteria | ☐ | Central | ■ | Design Dev | ■ |
| Gym | ☐ | Mountains | ■ | Contract Docs | ■ |
| Corridors | ☐ | Desert | ■ | Construction | ■ |
| Administration | ☐ | | | Commissioning | ☐ |
| Toilets | ☐ | | | Operation | ■ |
| Other | ☐ | | | | |

## Applicable Codes

Title 22, Recycled Water Uses Allowed in California. See http://www.watereuse.org/Pages/legislative.html.

California Water Code. Web site "Water Laws and Regulations" of the California State Water Resources Control Board, http://www.swrcb.ca.gov/water_laws/index.html contains includes link to the Water Code.

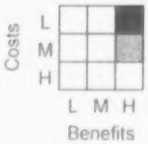
California Plumbing Code, Appendix G, Graywater Code.

## Integrated Design Implications

- Irrigation systems using graywater systems must be integrated with indoor plumbing design.
- Rainwater collection systems must be integrated with roofing design and selection. For example, redwood, cedar, and treated wood shingle/shake roofs can leach toxic substances when wet. Additionally, rainwater from asphalt shingle roofs should not be used to irrigate food-producing gardens. Roofs must be sufficiently sloped.

## Costs

Modest capital cost. Unit costs drop with larger flows and landscaped areas. Cost savings due to reduced potable water use offsets capital costs.



## Benefits

Landscaping irrigation is one of the highest water consumers in urban California. Using reclaimed water avoids using precious potable water resources for irrigation.

## Design Tools

None.

## Design Details

### Municipally-supplied Reclaimed Water

Some municipalities around the state provide non-potable water at very low cost for irrigation use. Contact your local water provider for availability. Piping changes are minimal because water is used for all irrigation. Care must be taken that the irrigated water does not pool or splash in areas where children may drink it, such as water fountains.

### Rainwater Collection

Simple rainwater collection systems comprise a rainbarrel at each rainwater leader or downspout. Rainbarrels should be equipped with first-flush devices to avoid storing water contaminated with bird droppings and dust. They should also incorporate an inlet screen and an overflow outlet. Overflow and drain valves should include hose couplings and discharge at least 6 feet away from foundations.

For collecting rainwater from roof areas:

- Use appropriate roofing materials such as metal, tile, or fiber cement. Lead-containing materials, such as flashing, should not be used in catchment roofs. Likewise, ensure that no zinc galvanized ridge caps, copper flashing, or copper wires for moss prevention are used. Asphalt composition roofs should not be used for collecting water for watering any food producing plants.
- Construct cistern or tank storage sized for the rainfall amount and roof size, with appropriate overflow devices. Cisterns can be made of concrete, ferro-cement, stone, or prefabricated metal, plastic, or fiberglass. Use only watertight, opaque materials and provide a cover.
- Provide an overflow route to direct excess flows away from building and in such a manner as to avoid impact to downstream properties.
- Install gutters and downspouts sized for the roof and rainfall intensity.
- Install screening devices or roof washers to filter out leaves, debris, and sediment that can clog the system.

For collecting and harvesting water from the soil surface and outdoor paved surfaces:

- Use open conveyances such as grass or gravel swales to direct and deliver harvested water to storage areas, such as small ponds, for reuse as irrigation water.
- Provide a pressurization system to deliver irrigation water.
- Incorporate aquatic plants to maintain storage pond's ecological balance.

### Graywater

Specify and install wastewater plumbing piping to capture graywater from showers, laundry, and bathroom sinks for subsurface irrigation of outdoors landscaping. Graywater piping should be labeled to distinguish it from other sanitary piping. Codes require that piping that carries non-potable water be colored purple.

A simple non-pumped gravity system is appropriate if leaching chambers or box troughs can be located downhill from the building, and maintenance staff is available for regular inspections and filter changes. Where maintenance staff is not expected, pumped systems equipped with automatically backwashed sand filters are most appropriate, though more expensive. These systems, unlike other graywater systems, can be used for drip irrigation of lawns and require minimal service.

Design to ensure graywater will not be exposed on the ground surface, even after prolonged rain.

Caution—Mini leachfields designed according to the California Plumbing Code have poor irrigation performance. See Ludwig's publications (listed in Additional Resources, below) for details.

## Operation and Maintenance Issues

- For graywater systems, regular inspection and maintenance are essential for non-automatic systems. Provide permanent documentation of maintenance procedures in the building.
- Maintenance of automatic systems should be handled by a service contract with firms specializing in graywater systems.
- Provide training and signage to promote maintenance staff awareness to signs of overdue maintenance or filter changes by obvious signals such as a visible overflow.
- Provide means to prevent the use of inappropriate cleansers and soaps, for example signage above sinks and purchasing requirements that ensure that only appropriate products are purchased.

## Commissioning

None.

## Example(s)

Windsor High School, Windsor, CA. School is completely irrigated with municipally provided reclaimed water. Designed by Quattrocchi / Kwok Architects

## References/Additional Information

California Department of Water Resources. 1416 - 9th Street, Room 1104-1, Sacramento, CA 95814, Phone (916) 653-6192, fax (916) 653-4684, http://wwwdwr.water.ca.gov.

State Water Resources Control Board, Water Recycling Programs, PO Box 1977, 1001 "I" Street 15th Floor, Sacramento, CA 95814-1977, phone 916/341-5536 for general inquiries, 916/341-5537 for construction related issues, email stormwater@dwq.swrcb.ca.gov, web site http://www.swrcb.ca.gov/recycling/index.html.

Texas Water Development Board. http://www.twdb.state.tx.us.

Builder's Greywater Guide: Installation of Greywater Systems in New Construction and Remodeling, *Art Lugwig, Oasis Design, Santa Barbara, CA, 1997, ($15), 805-967-9956, www.oasisdesign.net. Also available from IRIS Communications, Eugene, OR, 800-346-0104, shop.oikos.com/catalog.*

Greywater Handbook, *Peter Warshall and Associates, City of Malibu, Department of Environment, Building and Safety, 1995. A manual for design, construction, installation, operation and maintenance of greywater systems.*

Create an Oasis with Greywater, Your Complete Guide to Managing Greywater in the Landscape, Oasis Building Professionals Graywater Guide: the Guide to Professional Installation of Graywater Systems, *Art Lugwig, Oasis Design, Santa Barbara, CA, 805-967-9956, www.oasisdesign.net. Also available from IRIS Communications, Eugene, OR, 800-346-0104, shop.oikos.com/catalog. The Oasis Guides are excellent: brief, yet comprehensive, current and oriented to building professionals in Southern California.*

Products and manufacturers are listed in *GreenSpec* and the *REDI Guide*.

# Guideline SP13: Integrated Weed, Disease and Pest Management

## Recommendation

Control and manage weeds, disease and pests within tolerable limits in order to maintain the landscape in a manner that achieves attractive and healthy growth for plants, animals and people while conserving energy and water.

## Description

The most effective weed, pest and disease control measure is to keep plants healthy. When a problem is caused by an adverse environmental condition, chemically treating the problem will not prevent its recurrence, but will only be symptomatic treatment. Control of disease and pests includes, but is not limited to, rust, scale, aphids, mealy bugs, pine shoot moth, snails, rodents, etc.

Once viewed as safe and effective for insect control, chemical pesticides and herbicides are now recognized poisons that can contaminate the soil and harm wildlife and humans—especially children. Some of this poison finds its way into our lakes, streams, and groundwater supplies, where it disrupts the balance of life. Reducing the use of pesticides protects lakes and contributes to a healthier environment for fish, wildlife, and people.

*Integrated pest management is used to maintain this varied landscape. Photo courtesy of Wolfe Mason Associates.*

| Applicable Spaces | | Climates | | When to Consider | |
|---|---|---|---|---|---|
| Classrooms | ☐ | South Coast | ■ | Programming | ☐ |
| Library | ☐ | North Coast | ■ | Schematic | ☐ |
| Mulit-Purpose / Cafeteria | ☐ | Central | ■ | Design Dev | ■ |
| Gym | ☐ | Mountains | ■ | Contract Docs | ■ |
| Corridors | ☐ | Desert | ■ | Construction | ■ |
| Administration | ☐ | | | Commissioning | ☐ |
| Toilets | ☐ | | | Operation | ■ |
| Other | ☐ | | | | |

Integrated Pest Management (IPM) is a horticultural practice that stresses the application of biological and cultural pest control techniques with selective pesticides when necessary to achieve acceptable levels of control with the least possible harm to human health and safety, non-target organisms, and the environment. IPM encompasses various environmentally sound strategies, including—use of appropriate, adapted plant varieties; installation of a compatible, supportive landscape/site design (such as incorporating concrete mow strips near fencing to eliminate the need for herbicide use in these areas), providing the necessary nutrients and moisture; and following through with good maintenance practices.

## Applicability

All climates.

## Applicable Codes

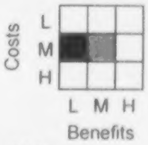
Healthy Schools Act (AB 2260). Signed into law in September 2000, this new legislation contains requirements for least toxic pest management practices and notification and documentation of pesticide use.

## Integrated Design Implications

Planning for IPM should be integrated/coordinated with Guideline SP13: *Landscaping Soil, Amendments and Mulch*, Guideline SP6: *Drought-tolerant and Pest-resistant Plants*, Guideline SP4: *Landscape Design & Management: Vegetation, Infrastructure and Natural Lawn Care*, Guideline SP2: *Landscaping to Provide Shade to Buildings and Paved Areas*, and Guideline SP7: *Location of HVAC Equipment*.

Landscape design that employs Integrated Pest Management (IPM) will help limit the release of potential stormwater pollutants.

## Costs



Medium. Integrated Pest Management may have a higher initial cost than pesticide programs, but it is cost-effective over the life of the building and produces safer school grounds, healthier vegetation, and lower spraying costs. Frequent pesticide use can result in a chemical dependent situation, where an insect comes back stronger than it was before. Increasing doses and frequency of application are then needed for attempted control of the pest. For example, pesticides that kill aphids also kill aphid predators. Since aphids reproduce more quickly than their predators, when they return to the plant, their natural enemies will be gone, and they may also become resistant to the pesticide. IPM means less pesticide/herbicide use, but may entail additional ongoing labor for maintenance as well as additional training, documentation, and policy development costs.

## Benefits

Decreased pesticide use means less health risk to students and staff and lower maintenance costs associated with the purchase of pesticides.

## Design Tools

None.

## Design Details

There are four key issues for weeds, disease and pests:

- The planting of appropriate species and their maintenance in a healthy condition since most weeds and pests are attracted to weak or over fertilized plants much more quickly than to those in good health.
- Determining what really is a weed or pest. A plant is a weed only if it is in an undesirable location or is out-competing more desired species. Many 'bugs' are essential to plant propagation and are beneficial to the health of plant.
- Maintaining weeds and pests on vegetation (grass, groundcover and shrubs, grasses and turf, gardens and perennials) within tolerable levels using the Integrated Pest Management (IPM) approach.
- The control of damage from water fowl, gophers and other rodents by the replacement of inappropriate plants with those that are less susceptible, and the addition of mechanical protection devices (cages, mesh, etc.) during the early growth period of the new plants, as needed.

Recommend consultation with a landscape professional with expertise in integrated pest management to identify landscape and site design strategies that will support ongoing IPM. Select plant species less prone to disease.

Perform weed control by hand pulling and hoeing whenever possible. It is important to do this frequently enough so that weeds to not have a chance to go to seed. Remove weeds from pavement and all vegetative areas. If there is a persistent problem, a pre-emergent herbicide may be considered with approval from the large or particularly troublesome areas *only* after review and approval.

Integrated Pest Management requires a proactive management program with a good system of monitoring and record keeping as the first line of defense. Contractors' monthly reports shall include all weed, pest or disease observations and actions taken for review by the management team. Mechanical and biological control measures, such as hand picking, water jets, safer soap, barriers (e.g. Tree Tanglefoot or poly mesh), biological controls (e.g. *Bacillus thurengiensis*), less toxic sprays (e.g. dormant/summer oil, sulfur fungicides, pyrethrum, or rotenone) are first considered for use, often in combination. Less toxic chemicals such as 'Round-Up' will be considered before stronger chemicals.

The control of pests is the subject of much recent research, particularly in grass areas. Herbicides and sprays used to eliminate broadleaf weeds or fungus have caused numerous injuries, studies and debates. If grass areas are properly located and receive proper care, weeds and disease should not be a major problem. If problems do arise, they are to be reviewed with the consulting architect and physical or biological solutions explored before chemicals are requested for use. Broadleaf weeds are to be kept to a minimum but multiple grass varieties are acceptable. The use of green dyes in particularly noticeable brown spots is an option.

### Operation and Maintenance Issues

IPM is different and requires planning, education, and training to succeed. Each school district should develop and implement a written pest management policy.

### Commissioning

None.

### Example(s)

"The Pesticides Reduction in Schools (PRI- School) Project" sponsored IPM demonstration sites at two public schools Peabody Charter School in the Santa Barbara School District and Vista de las Cruces School in the Vista del Mar District, both within Santa Barbara County.

### References/Additional Information

California Department of Pesticide Regulation, http://www.cdpr.ca.gov. The web site provides information about the new Healthy Schools Act and CPR's school IPM program.

*Overview of Pest Management Policies, Programs, and Practices in Selected California Public School Districts.* This is a report of a study conducted by the Environmental Monitoring and Pest Management Branch of the Department of Pesticide Regulation (DPR) of pest management programs in California's public school districts. The study was conducted in cooperation with the California Department of Education (CDE) to: (1) obtain an overview of district pest management policies, programs, and practices, (2) identify policy and program constraints, and (3) identify ways that DPR can work cooperatively with CDE to assist school districts in implementing pest management programs based on the principles of integrated pest management (IPM). The report is available on-line at http://www.cdpr.ca.gov/docs/dprdocs/schools/schools.htm.

*Reducing Pesticides in Schools: How Two Elementary Schools Control Common Pests Using Integrated Pest Management Strategies*, The Pesticides Reduction in Schools (PRI- School) Project explored the potential for reducing risks associated with unnecessary pesticide use by implementing Integrated Pest Management (IPM) programs in schools throughout Santa Barbara County. The main goals of the project were to identify the local administrative, technical and social barriers to implementing effective IPM programs and to explore ways to overcome these barriers. Funding for the PRI- School Project was provided by the U. S. Environmental Protection Agency and the Santa Barbara Foundation. The project was managed jointly by the Community Environmental Council (CEC) and Organic Consulting Services, both from Santa Barbara, Calif. The report is available online at http://grc.org/cec/pubs/IPM_report2.html.

University of California's Statewide Integrated Pest Management Project, web site: http://www.ipm.ucdavis.edu/default.html.

# Guideline SP14: Groundwater Management

**Recommendation**

Manage ground water separately from surface water.

**Description**

In areas where the water table is high, construction of a new building can result in seepage of groundwater to the surface. Strategies to manage this water separately from other surface water, which is potentially contaminated and discharges into the stormwater system, protects groundwater quality and provides opportunity for this uncontaminated groundwater to infiltrate back into the ground. Strategies include the use of level spreaders, piping the discharge from curtain drains to trickle discharge onto fields or wetlands in lieu of the stormwater system, and using an infiltration system for rooftop runoff.

*Part of a comprehensive site protection program, the groundwater management system for construction of the new Sonoji Sakai Intermediate School in Bainbridge Island, Washington, keeps ground water separate from stormwater, preserves on-site wetlands, protects the school building, and reduced the required size of the detention pond. The project won an Earth Day Award from the County for their environmental building efforts.*

| Applicable Spaces | |
|---|---|
| Classrooms | ☐ |
| Library | ☐ |
| Mulit-Purpose / Cafeteria | ☐ |
| Gym | ☐ |
| Corridors | ☐ |
| Administration | ☐ |
| Toilets | ☐ |
| Other | ☐ |

| Climates | |
|---|---|
| South Coast | ■ |
| North Coast | ■ |
| Central | ■ |
| Mountains | ■ |
| Desert | ■ |

| When to Consider | |
|---|---|
| Programming | ☐ |
| Schematic | ☐ |
| Design Dev. | ■ |
| Contract Docs. | ■ |
| Construction | ■ |
| Commissioning | ☐ |
| Operation | ■ |

**Applicability**

This applies in areas with a high ground water table, which will most likely occur in the north coast region.

**Applicable Codes**

State Water Resources Control Board, Storm Water Program, PO Box 1977, 1001 "I" Street 15th Floor, Sacramento, CA 95814-1977, phone 916/341-5536 for general inquiries, 916/341-5537 for construction related issues, e-mail stormwater@dwq.swrcb.ca.gov, or Internet http://www.swrcb.ca.gov/stormwtr/index.htm.

CERES (The California Environmental Resources Evaluation System), http://www.ceres.ca.gov/index.html features the LUPIN (The California Land Use Planning Network) wysiyg://16/http://ceres.ca.gov/planning/ with a broad array of data types from diverse sources, including selected but fully scanned and searchable county and city zoning ordinances.

**Integrated Design Implications**

To realize potential savings, the design should be integrated with design of site built stormwater systems

**Costs**

Costs will vary with the size and complexity of the system, but will entail additional capital costs.

| Costs | L | M | H |
|---|---|---|---|
| L | ☐ | ☐ | ☐ |
| M | ☐ | ☐ | ■ |
| H | ☐ | ☐ | ▨ |

Benefits

**Benefits**

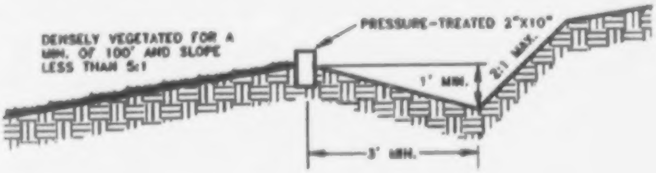
The complexity or size of site built stormwater systems can potentially be reduced, decreasing overall construction costs. Protects and preserves ground water quality and quantity.

## Design Tools

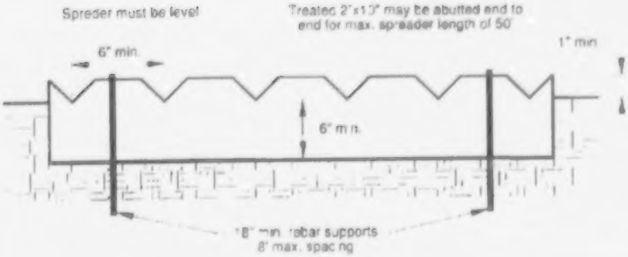
Applicable state and local stormwater and surface water management design manuals.

## Design Details

Level spreaders change be used when a concentrated flow of water needs to be dispersed over a large area with existing stable vegetation.


DENSELY VEGETATED FOR A MIN. OF 100' AND SLOPE LESS THAN 5:1
PRESSURE-TREATED 2"X10"
1' MIN.
2:1 MAX.
3' MIN.

Cross Section of Level Spreader


Spreder must be level
Treated 2"x10" may be abutted end to end for max. spreader length of 50'
6" min.
1" min
6" min.
18" min. rebar supports 8' max. spacing

Detail of Level Spreader

*Figure 2 – Level Spreader, Cross Section & Detail*

*(Source: Washington State Department of Ecology, Stormwater Management Manual for Western Washington, Volume II, Construction Stormwater Pollution Prevention)*

## Operation and Maintenance Issues

Will depend upon strategies used. For example, level spreaders should be inspected after every runoff event to ensure they are functioning correctly.

## Commissioning

NA

## Example(s)

Sonoji Sakai Intermediate School, Bainbridge Island School District, Bainbridge Island, Washington uses level spreaders to slowly distribute groundwater to the adjacent field and wetlands.

## References/Additional Information

Stormwater and Urban Runoff Seminars—Guide for Builders and Developers, NAHB, Edited by Susan Asmus, Washington DC, 800-368-5242 x538 or http://www.nahb.com.

International Erosion Control Association (IECA). 800-455-4322 or http://www.ieca.org. Provides technical assistance and an annual Erosion Control Products and Services Directory. IECA's Western Chapter addresses issues that are unique to the Western U.S

Stormwater Management For Construction Activities: Developing Pollution Prevention Plans And Best Management Practices: Summary Guidance. EPA#833-R-92-001, October 1992, EPA Office of Wastewater Management, 401 M St. SW, Mail Code EN-336, Washington DC, 20460. 800-245-6510, 202-260-7786 or www.epa.gov/owm/sw/construction/.

State Water Resources Control Board, PO Box 1977, 1001 "I" Street 15th Floor, Sacramento, CA 95814-1977, phone 916/341-5536 for general inquiries, 916/341-5537 for construction related issues, e-mail stormwater@dwq.swrcb.ca.gov, or Internet http://www.swrcb.ca.gov/index.html.

# Guideline SP15: On-Site Wastewater Treatment

## Recommendation

Consider on-site wastewater treatment.

## Description

On site wastewater treatment can be provided by means of a constructed wetland or Living Machine®. Constructed wetlands treatment systems are engineered systems that have been designed and constructed to utilize the natural processes involving wetland vegetation, soils, and their associated microbial assemblages to assist in treating wastewater.

Invented by Dr. John Todd of Living Machines, Inc., Living Machines® are on-site wastewater treatment systems that incorporate and accelerate natural processes to purify water.

## Applicability

All climates.

## Applicable Codes

Applicable state and municipal health codes.

## Integrated Design Implications

Interface with site planning and wastewater systems design.

## Costs

Costs for both constructed wetlands and Living Machines® are higher than conventional design for connection of wastewater to municipal systems. Long-term savings in municipal sewage fees offsets capital costs.

*Arcata, with a population of approximately 15,000, is a diverse community whose resourcefulness and integrity has demonstrated that a constructed wetland system can be a cost efficient and environmentally sound wastewater treatment solution. (Source: Arcata, California - A Natural System for Wastewater Reclamation and Resource Enhancement, http://www.epa.gov/owow/wetlands/construc/arcata.html)*

| Applicable Spaces | | Climates | | When to Consider | |
|---|---|---|---|---|---|
| Classrooms | ☐ | South Coast | ■ | Programming | ■ |
| Library | ☐ | North Coast | ■ | Schematic | ■ |
| Mulit-Purpose / Cafeteria | ☐ | Central | ■ | Design Dev | ■ |
| Gym | ☐ | Mountains | ■ | Contract Docs | ■ |
| Corridors | ☐ | Desert | ■ | Construction | ■ |
| Administration | ☐ | | | Commissioning | ■ |
| Toilets | ☐ | | | Operation | ■ |
| Other | ☐ | | | | |

## Benefits

Provides on-site waste water treatment, reducing the load on municipal systems, providing treatment where connection to municipal systems is not feasible, and providing opportunity for education.

## Design Tools

Hammer, D.E. and R.H. Kadlec. 1983. Design Principles for Wetland Treatment Systems. EPA-600/S2-83-026. EPA Municipal Environmental Research Lab, Cincinnati, OH

Living Machine® are designed and installed by Living Machines, Inc.

| Costs | L | M | H |
|---|---|---|---|
| L | | | |
| M | | | |
| H | ■ | | |

Benefits

## Design Details

*Open aerobic reactors at Darrow School, New Lebanon, NY.* http://www.livingmachines.com/htm/study3.htm), *Copyright 2000, Living Machines, Inc.* Reprinted with permission.

Constructed wetlands treatment systems are designed to take advantage of many of the same processes that occur in natural wetlands, but do so within a more controlled environment. Some of these systems have been designed and operated with the sole purpose of treating wastewater, while others have been implemented with multiple-use objectives in mind, such as using treated wastewater effluent as a water source for the creation and restoration of wetland habitat for wildlife use and environmental enhancement.

Constructed wetlands treatment systems generally fall into one of two general categories: "Subsurface Flow Systems" and "Free Water Surface Systems." Subsurface flow systems are designed to create subsurface flow through a pervious medium, keeping the water being treated below the surface, thereby helping to avoid the development of odors and other nuisance problems. Such systems have also been referred to as "root-zone systems," "rock-reed-filters," and "vegetated submerged bed systems." The media used (typically soil, sand, gravel or crushed rock) greatly affect the hydraulics of the system. Free water surface systems, on the other hand, are designed to simulate natural wetlands, with the water flowing over the soil surface at shallow depths. Both types of wetlands treatment systems typically are constructed in basins or channels with a natural or constructed subsurface barrier to limit seepage.

In a Living Machine®, a diversity of organisms—including bacteria, plants, zooplankton, and other invertebrates—break down and digest organic pollutants, with the help of sunlight and a managed environment. Depending on the climate, Living Machines® can be housed in a protective greenhouse, under light shelter, or in the open air. With effluent polishing, Living Machines® produce a high quality effluent that is suitable for re-use or a number of disposal alternatives, such as landscape irrigation, toilet flushing and vehicle washing.

## Operation and Maintenance Issues

Ongoing monitoring of effluent to verify compliance with final discharge requirements.

## Commissioning

NA

## Example(s)

*Oberlin College*—The Living Machine® is one of several ecological design features in the Adam Joseph Lewis Center for Environmental Studies at Oberlin College, Oberlin, OH. The Living Machine® treats wastewater using a system of engineered ecologies that include microbes, plants, snails and insects, and is designed to treat up to 2,000 gallons of the building's wastewater daily in a garden-like atmosphere. Upon completion of a water pressurization system, the treated wastewater will be recycled back through the building for non-potable re-use.

*Darrow School* is a private residential high school, of 90 students, located on an old Shaker community site tucked away in the scenic Berkshire Mountains. Several years ago, Darrow School administrators found they needed to replace an aging septic system. Instead of traditional septic tanks and leach fields, they decided to purchase a Living Machine® to meet their wastewater needs. Besides processing the school's wastewater, the Living Machine® provides a setting for a wide variety of educational activities.

The *Living Machine®* is an integral part of the School's new Samson Environmental Center. The Center was designed using principles of sustainability and environmental construction. The innovative nature of the Living Machine®, coupled with the educational programs that tie into its use, draw positive outside attention to the school, its mission and philosophy. (http://www.livingmachines.com/htm/study3.htm).

Darrow School, 110 Darrow Road, New Lebanon, NY 12125, Telephone: 518/794-6000, Fax: 518/794-7065

**References/Additional Information**

Living Machines, Inc. has built more than 20 commercial-scale wastewater treatment facilities in six countries for such clients as M&M Mars, Master Foods, the Body Shop, National Audubon, the State of Vermont, Battelle Foundation and U.S. EPA, ranging in size from 4,000 to 1,000,000 gallons per day. (http://www.livingmachines.com/htm/machine.htm)

Allen, G.H. and R.H. Gearheart (eds). 1988. Proceedings of a Conference on Wetlands for Wastewater Treatment and Resource Enhancement, Humbolt Sate Univ., Arcata, CA

EPA web site, Constructed Wetlands for Wastewater Treatment and Wildlife Habitat, http://www.epa.gov/owow/wetlands/construc/content.html.

Reed, S.C., E.J. Middlebrooks, R.W. Crites. 1988. Natural Systems for Waste Management & Treatment. McGraw Hill, New York, NY

# INTERIOR SURFACES AND FURNISHINGS

This chapter provides guidelines for:

| Guideline | Applicable CSI Section |
|---|---|
| Carpeting (Guideline IS1) | Division 9 |
| Resilient flooring (Guideline IS2) | Division 9 |
| Ceramic tile/terrazzo for walls/flooring (Guideline IS3) | Division 9 |
| Concrete flooring (Guideline IS4) | Division 3 |
| Wood flooring (Guideline IS5) | Division 6 |
| Bamboo flooring (Guideline IS6) | Division 9 |
| Gypsum board for walls/ceilings (Guideline IS7) | Division 9 |
| Concrete masonry for walls (Guideline IS8) | Division 4 |
| Acoustical walls and ceilings (Guideline IS9) | Division 9 |
| Paints and coatings (Guideline IS10) | Division 9 |
| Casework and trim (Guideline IS11) | Division 6 |
| Interior doors (Guideline IS12) | Division 8 |
| Toilet partitions (Guideline IS13) | Division 10 |

## Overview

The guidelines in this section govern selection of flooring, wall and ceiling finishes, other interior surfaces, and their associated coatings and adhesives. The guidelines focus on materials-efficient products that do not degrade indoor environmental quality. Environmental priorities should be judged in the context of the standard considerations of the application (gym vs. classroom), project budget, overall performance and availability.

When selecting materials for interior surfaces and furnishings for a high performance school, designers look for cost-effective, durable and materials-efficient products that provide the desired acoustical performance and aesthetic qualities, and protect indoor air quality and health. In addition, high performance school designers seek to minimize the impact on the natural environment by selecting locally produced materials and materials produced in an environmentally benign manner, preferring suppliers and manufacturers that practice "sustainable" or environmentally conscious management principles.

The selection process should consider installation and maintenance requirements as well as how the material or furnishing performs during its service life. Many benign finishes must be installed using adhesive, sealants or coatings that are toxic and/or emit volatile chemicals ("off-gas") during and after installation. Look for those products that use nontoxic, low-VOC, water-based adhesives and coatings. It is also important to select materials that do not require the use of toxic cleaning supplies for ongoing maintenance and are not susceptible to moisture damage that can foster mold growth.

Because of their high visibility, interior surfaces and furnishings provide an excellent opportunity to highlight the high performance approach taken with the school. Environmentally preferable choices teach the importance of caring for our health and the health of our natural environment.

## Goals for Interior Surfaces and Finishes Selection

Interior surfaces design and selection for a high performance school seeks to achieve one of more of the following three primary goals:

- Protect indoor environmental quality
- Promote materials efficiency
- Promote other environmentally preferable alternatives

### Healthy Interiors—Protecting Indoor Environmental Quality

With regard to the high density and young age of a school building's occupants, most of whom are children or adolescents with still-developing respiratory systems, protecting the school building's indoor environmental quality is a fundamental goal in the design of a high performance school. Common problem substances from construction include formaldehyde, volatile organic compounds (VOCs) that off-gas from many interior surface materials, dust and moisture.

- *Formaldehyde.* Formaldehyde is a component of many building materials. In the indoor environment, formaldehyde can cause several health problems for occupants, including headaches and flu-like symptoms, and can be a cause of sick building syndrome.
- *VOCs.* VOCs refer to a class of compounds regulated by the U.S. Environmental Protection Agency (EPA) that react photochemically in the outdoor environment to produce smog. They include many solvents commonly found in adhesives, caulks, paint and other coatings. They are found in other interior surface materials as well, such as many textiles. VOC-containing substances will emit volatile chemicals ("off-gas") during and after application, which, like formaldehyde, can cause health problems for workers and occupants.

  VOC emissions are highest immediately after the finish is applied, but can continue for days, weeks or even months. Even with "low-VOC" materials, it is important to ventilate the space thoroughly during and after each application. Otherwise, emitted gases will adhere to porous surfaces (such as carpet, furniture and drywall) and later be re-released into the indoor environment. The required venting period depends on the amount of surface covered and the toxicity of the finish. For toxic finishes applied over large areas, specify venting for seven days.

Emissions are of concern not only for paints, sealants and adhesives, but also for many other interior components, including some furnishings and casework materials. Labeling requirements for finishes provide a straightforward way to compare VOC content and toxicity. Analogous comparisons for furniture, however, are more complex. The EPA and the American Society for Testing and Materials (ASTM) have developed a standard chamber test method that measures product emissions under controlled conditions[5]. Also, the Greenguard IAQ Registry is a new web-based product registry from Air Quality Sciences, Inc. that lists products meeting widely referenced IAQ guidelines. (See Resources below for more information). Be sure to request and evaluate emissions test data, performed in accordance with ASTM D5516-90, from manufacturers for comparative products. Also, ensure that VOC limits are clearly stated in the specifications for the project, either in General Conditions, or in each section that contains adhesives, sealants, coatings, flooring (carpets and hard), and composites woods.

Designers must be aware, however, that a product can be "low-VOC" or even zero-VOC and still contain odorous, toxic or otherwise undesirable ingredients such as ammonia, acetone, odor masking agents, or many other compounds, including fungicides and bactericides. Some of these may not be an *air quality* problem for occupants, but they may be hazardous to installers and manufacturers. In addition, hazardous ingredients can degrade the natural environment during production and after disposal. An effective material selection process will not only look at the VOC content but will include a thorough review of the product's Material Safety Data Sheet (MSDS). (See discussion of Material Safety Data Sheets in the Material Selection and Research section in the Introduction to Volume II.)

- *Dust.* Construction activities such as wood sanding generate large amounts of dust and debris, which can become an indoor air quality problem. Thoughtful work practices and thorough cleaning before occupancy will mitigate this potential problem.
- *Moisture.* Excess humidity can promote the growth of mold and other biological contaminants that cause indoor air quality problems.

To protect indoor environmental quality then, the designer should seek to eliminate potential sources of indoor air pollution by selecting nontoxic, low-emitting, moisture-resistant materials that can be safely installed and maintained. The approval process for substitutions should be clearly spelled out and should require specific product ingredient information, as well as information about any adhesives, solvents or other materials that might be used during installation or maintenance. However, do not prohibit substitutions. Specialized subcontractors can be a superb source of information about new and improved product alternatives.

In addition to product selection, the designer should also look for other ways to mitigate potential indoor environmental quality problems during construction. Strategies include specifying the required sequence of work (for example, installing soft finishes after painting); the required duration of ventilation during and after installation; the protection of ducts and the ventilation system during flushout; and any isolation needed during renovations. Requirements such as these will be in the General Conditions and related sections of the construction specifications.

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[5] ASTM D5116-90, Small Scale Environmental Determination of Organic Emissions from Indoor Materials/Products

Interior surface materials also affect other aspects of a healthy indoor environment, such as visibility, acoustical comfort and teaching the environment. The type and color of surfaces and furnishings can also affect visual comfort and lighting efficiency.

In summary, objectives and strategies used to protect indoor environmental quality include selecting interior surfaces that are:

- Made with water-based coatings and adhesives
- Nontoxic and non-polluting during installation and use
- Resistant to moisture or inhibit the growth of biological contaminants
- Easy to clean with non-polluting maintenance products
- Sound dampening
- Visually comfortable

### Promoting Materials Efficiency

Interior finishes are important from a resource conservation perspective because we use them in large amounts and because they wear, requiring periodic maintenance or replacement. For these reasons, it is important to emphasize durability, recycled content, reusability, recyclability and use of rapidly renewable source materials. Many interior building products are now available that are materials efficient in one or more of these ways.

One example of materials-efficient wood use is engineered lumber, which can be used for casework and trim as well as for framing. Engineered lumber is manufactured by combining wood fibers with plastic resins to produce high quality, structural products such as I-joists, laminated veneer lumber (LVL), parallel strand lumber (PSL), and glue-laminated beams. Sheathing products manufactured in this manner, such as oriented strand board (OSB), wafer board and particleboard, are made primarily of sawmill waste. Likewise, finger-jointed lumber made from wood scraps makes use of material that would otherwise be wasted. And composite lumber composed of particleboard with a veneer of hardwood makes efficient use of fine hardwood for uses such as paneling and doors.

Objectives and strategies used to promote materials efficiency include selecting materials that are:

- Durable
- Movable, refinishable and reusable
- Recyclable
- Made from or use resources from the earth that are sustainable

- Made with recycled content. The use of recycled content materials helps address problems of solid waste disposal, energy used during manufacture, and the consumption of natural, virgin resources.

The design process also offers opportunity to maximize materials efficiency through the use of standard dimensions that reduce waste during construction.

### Other Environmental Considerations

Embodied energy is the energy consumed during the entire life cycle of a product, including resource extraction, manufacturing, packaging, transportation, installation, use, maintenance, and when appropriate, even disposal. Products with low embodied energy are environmentally preferable. Since transportation is a component of embodied energy, give preference to products that are locally available.

Products that are produced in a way that protects the eco-system are also environmentally preferable. One example is certified wood products, which are produced from trees grown and harvested from sustainably managed forests.

Other environmental objectives and strategies include selecting materials that are:

Low in embodied energy (including locally available)

Eco-system protective

Table 5 summarizes the interior surfaces goals and objectives described above and presents the predominant relationship between them and the guidelines that follow.

*Table 5 – Interior Surfaces Goals and Relationship to Guidelines.*

| **Interior Surfaces Goal** | **Guideline** |
|---|---|
| *Objective/Strategy* | |
| **Protect Indoor Environmental Quality** | |
| *Use water-based coatings and adhesives* | All, where applicable. |
| *Use nontoxic/non-polluting materials* | All, where applicable. |
| *Use moisture-resistant materials* | Guideline IS4: Concrete flooring |
| | Guideline IS3: Ceramic tile/terrazzo |
| *Low/non-polluting maintenance* | Guideline IS4: Concrete flooring |
| | Guideline IS3: Ceramic tile/terrazzo |
| | Guideline IS5: Wood flooring |
| | Guideline IS6: Bamboo flooring |
| | Guideline IS8: Concrete masonry for walls |
| | Guideline IS13: Toilet partitions |
| *Use sound-dampening materials* | Guideline IS1: Carpeting |
| | Guideline IS9: Acoustical walls and ceilings |

*Table 5 – Interior Surfaces Goals and Relationship to Guidelines.*

| Interior Surfaces Goal | Guideline |
|---|---|
| **Materials Efficiency** | |
| *Made from or use resources from the earth that are sustainable* | Guideline IS2: Resilient flooring (linoleum) |
| | Guideline IS6: Bamboo flooring |
| | Guideline IS5: Wood flooring (if certified wood) |
| | Guideline IS12: Interior doors (if certified wood) |
| | Guideline IS11: Casework and trim (biocomposites, bamboo, certified wood) |
| *Made with recycled content* | Guideline IS1: Carpeting |
| | Guideline IS2: Resilient flooring |
| | Guideline IS3: Ceramic tile/terrazzo for walls/flooring |
| | Guideline IS4: Concrete flooring |
| | Guideline IS7: Gypsum board for walls/ceilings |
| | Guideline IS9: Acoustical walls and ceilings |
| | Guideline IS13: Toilet partitions |
| *Recyclable* | Guideline IS1: Carpeting |
| | Guideline IS5: Wood flooring |
| | Guideline IS7: Gypsum board for walls/ceilings |
| | Guideline IS9: Acoustical walls and ceilings |
| | Guideline IS4: Concrete flooring |
| | Guideline IS8: Concrete masonry for walls |
| *Movable, refinishable and reusable* | Guideline IS5: Wood flooring |
| | Guideline IS11: Casework and trim |
| | Guideline IS12: Interior doors |
| | Guideline IS13: Toilet partitions |
| **Other Environmental Considerations** | |
| *Locally available* | Most. Exceptions: Bamboo flooring (which is domestically manufactured with raw materials imported from China); low emissions, recycled content carpet (no California manufacturers); recycled content plastic toilet partitions (widely available, but no CA mfrs); recycled content ceramic tile (no CA mfrs.). |
| *Durable* | Guideline IS2: Resilient flooring |
| | Guideline IS3: Ceramic tile/terrazzo for walls/flooring |
| | Guideline IS4: Concrete flooring |
| | Guideline IS5: Wood flooring |
| | Guideline IS6: Bamboo flooring |
| | Guideline IS7: Gypsum board for walls/ceilings (especially recycled content, high impact gypsum) |
| | Guideline IS8: Concrete masonry for walls |
| *Low in embodied energy* | Guideline IS5: Wood flooring |
| *Eco-system protective* | Guideline IS2: Resilient flooring |
| | Guideline IS5: Wood flooring (if certified) |
| | Guideline IS11: Casework and trim |
| | Guideline IS12: Interior doors |

The discussions below provide a summary of the specific considerations, advantages and disadvantages of materials choices addressed in the Interior Surfaces Guidelines. For more information on selecting environmentally preferable products, see Material Selection and Research in the Introduction to Volume II.

## Flooring

Flooring should be durable to withstand heavy use without requiring frequent replacement, easy to maintain, recyclable, and contribute to a healthy and comfortable indoor environment. Based on life-cycle costs, highly durable materials are justified, especially for high-use areas.

Adhered carpet systems require a high level of maintenance, and their need for frequent replacement makes them materials- and energy-intensive over their lifetime. However, carpeting offers first cost, acoustical and comfort benefits that are generally not available with other flooring choices. For these reasons, carpeting is often used in classrooms and administrative areas.

The healthiest floor choices are hard, easy-to-clean, smooth surfaces such as resilient flooring, concrete, tile and wood, which do not harbor dust or other allergenic particles. Smooth floors are also more durable than carpet, so they cost less per year of use. Hard surfaces are often selected for use in all areas except classrooms and administrative areas.

Table 6 summarizes advantages and disadvantages of the flooring choices addressed in these guidelines.

*Table 6 – Environmental Criteria for Floors*

| *Flooring Type* | *Advantages* | *Disadvantages* |
|---|---|---|
| Carpet<br>Guideline IS1 | Materials-efficient options available.<br>Carpet & Rug Institute's IAQ "Green Label" available.<br>Thermal comfort.<br>Physical comfort (cushion).<br>Noise control. | Emits VOCs during and after installation.<br>Can harbor dust and other allergy-causing particles.<br>High maintenance. Requires frequent vacuuming, which stirs up dust.<br>Can adsorb VOCs and re-emit later.<br>Adhesives and maintenance products can add to indoor pollution load (but low-toxic/low-VOC options are available).<br>Need to allow time to air out carpet before occupancy.<br>Less durable and stains easier than other flooring options.<br>Significant debris generated when it must be replaced. Limited recycling options. |
| Resilient Flooring<br>Guideline IS2 | Low first cost and highly durable—costs less per year of use than carpet.<br>Easy to clean.<br>Environmentally preferable options (such as recycled content) available, though these tend to cost more.<br>High reflectivity can enhance daylighting. | Adhesives and maintenance products can add to indoor pollution load (but low-toxic/low-VOC options are available).<br>Toxic byproducts are produced in the manufacture of commonly used vinyl flooring. Also, its primary component, polyvinyl chloride (PVC), has the potential for VOC off-gassing. When combusted, vinyl creates toxic dioxins. Limited recycling options for vinyl. For these reasons, vinyl flooring should be avoided.<br>Most are not recyclable or biodegradable. |
| Ceramic Tile / Terrazzo<br>Guideline IS3 | Recycled content options available.<br>Easy to clean and stain-resistant (must be sealed first).<br>Highly durable.<br>High reflectivity can augment daylighting. | High cost.<br>High embodied energy.<br>Made from nonrenewable resources. Non-recyclable.<br>Tile installation materials (mortar and grout) are sources of VOCs and toxic materials. (Portland cement-based mortar and grout appear to have less significant environmental impact than latex or solvent-based systems.)<br>Terrazzo poses installation risks, depending upon type. (Cementitious type appears to have less significant environmental impacts than epoxy systems.)<br>Hard finished surface, can compromise physical comfort.<br>Adhesives and maintenance products can add to indoor pollution load (but low-toxic/low-VOC options are available). |
| Concrete Flooring<br>Guideline IS4 | Materials efficient.<br>Highly durable.<br>Low maintenance and low cost. | Sealers and wax products can add to indoor pollution load (but low-toxic/low-VOC options are available). |
| Wood Flooring<br>Guideline IS5 | Renewable resource, if properly managed (certified forests).<br>Low embodied energy.<br>Wood flooring is recyclable and the market for recycled wood flooring is expanding.<br>Biodegradable.<br>Easy to clean.<br>"Warm," comfortable surface.<br>Durable and can be refinished to prolong its life and good aesthetics. | High cost.<br>Adhesives, sealants, and maintenance products can add to indoor pollution load (but low-toxic/low-VOC options are available).<br>Requires special moisture-prevention care in handling and installation to prevent later IAQ problems.<br>On-site sanding requires special measures. |
| Bamboo Flooring<br>Guideline IS6 | Materials efficient.<br>Durable and hard.<br>Easy to clean.<br>"Warm," comfortable surface. | High cost.<br>Adhesives, sealants, and maintenance products can add to indoor pollution load (but low-toxic/low-VOC options are available). |

## Walls and Ceilings

Walls and ceilings should be durable, easy to clean, recyclable, and contribute to a healthy and comfortable indoor environment. Classrooms and other rooms require plenty of tackable wall space for teaching aids and displaying student projects. The type and color of surfaces on teaching walls should also be visually comfortable and not detract from teacher presentations.

Drywall is potentially recyclable and can be composted. Recycled content drywall is available, but it is important to specify recycled content to make sure you get it.

When using wall coverings, use biodegradable papers that contain recycled paper or fiber content. Vinyl wall coverings are widely used but are discouraged for high performance schools because they are manufactured from polyvinyl chloride (PVC). (PVC-based products are banned in some areas of Europe because of off-gassing of VOCs and creation of toxic byproducts during manufacture.) Installation of wall coverings using traditional wallpaper paste is preferable to using self-stick wall coverings, due to the levels of VOC content in the adhesive.

Avoid using ceiling tile and sprayed-on ceiling finishes containing asbestos, formaldehyde, or crystalline silica, as these items are possible cancer and respiratory tract hazards. According to a Cornell University study, the one cause of sick building syndrome (SBS) is exposure to mineral fibers (rock wool or fiberglass). Furthermore, these fibers do not decompose in a landfill.

Table 7 summarizes advantages and disadvantages of the wall and ceiling choices addressed in these guidelines.

*Table 7 – Environmental Criteria for Walls and Ceilings*

| *Type* | *Advantages* | *Disadvantages* |
|---|---|---|
| Gypsum Board<br>Guideline IS7 | Gypsum is highly recyclable if not contaminated (with paint or adhesives).<br>Recycled content gypsum is readily available at no cost premium, and the paper facing can be made with recycled paper.<br>Durable, high impact drywall contains up to 15% post-consumer recycled content.<br>Recycled gypsum is more durable than conventional wallboard.<br>Easy to repair.<br>Low cost. | Dust generated during sanding (can specify "wet sanding" process).<br>Gypsum surfaces are potent "sinks" for odors, which they can later re-release.<br>Requires periodic painting. Paints and primers can add to indoor pollution load (but low-toxic/low-VOC options are available).<br>Low durability compared to concrete block. |
| Ceramic Tile<br>Guideline IS3 | See Table 6, Ceramic Tile/Terrazzo Flooring. | See Table 6, Ceramic Tile/Terrazzo Flooring. |
| Concrete Masonry (CMU)<br>Guideline IS8 | High strength.<br>High fire resistance.<br>Highly durable.<br>Low maintenance.<br>The pigments typically used in colored CMU are nontoxic and contain none of the solvents associated with painting and re-painting.<br>Provides thermal mass. | Traditional CMUs absorb moisture in moist climates, which can lead to excessive indoor humidity.<br>If painted or coated, paints, sealers, and wax products can add to indoor pollution load (but low-toxic/low-VOC options are available).<br>Depending on style and type, may be less aesthetically pleasing than other wall types. However, a variety of colors, shapes, and textures are available. |
| Acoustical Walls and Ceilings<br>Guideline IS9 | Recycled content materials readily available.<br>Reclamation programs available (though limited).<br>Easy installation.<br>Acoustical ceiling tiles often cost less than wallboard ceilings.<br>Do not require painting or other finish materials to complete the installation.<br>Easy to reuse.<br>Provides for easy relocation of fixtures, if required. | Tile collects dust and adsorbs odors. Tile and plenum requires periodic maintenance.<br>Due to the grid organization, acoustical tile ceilings may not be as adaptable to renovations as a gypsum board ceiling.<br>If the T-bar ceiling space has a return air plenum, as is common, this type of air handling design is difficult to clean. Many materials are used in the space above the T-bar ceiling. Material off-gassing, odors and micro-organisms in the plenum area can spread and be distributed to other areas. (Avoid this by installing return air systems using dedicated metal ductwork with access hatches for inspection and cleaning.) |

## Coatings

Paints and other coatings affect indoor air quality and may produce toxic waste. Most conventional products off-gas VOCs, formaldehyde and other chemicals that are added to enhance product performance and shelf life. These toxic chemicals, especially in combination, pose health concerns. Fortunately, high quality, low-toxicity, and low-VOC substitutions are now available for all these products.

## Adhesives and Sealants

Many conventional construction adhesives, sealants, "acoustic" caulking, grouts, and mortars used to bond structural components are solvent based and toxic and may off-gas large amounts of toxic VOCs (including solvents and aromatic hydrocarbons). Avoid using these products, which include butyls and urethanes, indoors. Low VOC, low-toxic water-based, formulations are now available more many applications.

Specify the least toxic/lowest VOC product suitable for the application and require installer to use the smallest amount of adhesive necessary to fulfill the manufacturer's performance specifications for that product.

Non-solvent adhesives have 99% less hazardous emissions than solvent adhesives. Yellow and white glues are recommended. When specifying sealants, consider using only silicone sealants in interior areas. Other environmentally preferable alternatives include acrylics and siliconized acrylics. They are typically the safest to handle and have the lowest solvent content. All other sealant types, especially butyl sealants, emit VOCs and other toxic compounds.

## Applicable Codes

Applicable state and local school district design and materials standards.

California State Ventilation and Indoor Air Quality Code.

State of California, South Coast Air Quality Management District Rule #1168 for adhesives and sealants.

State of California, South Coast Air Quality Management District Rule #1113 for coatings (Note: Recently amended to adopt new, stricter VOC limits paint and other coatings.)

## Design Tools

Alevantis, Leon. 1996. *Reducing Occupant Exposure to Volatile Organic Compounds from Office Building construction Materials: Non Binding Guidelines.* Published by the CA Department of Health Services. Available online at http://www.cal-iaq.org/VOC.

American Society of Heating, Refrigerating and Air-conditioning Engineers (ASHRAE). *ASHRAE Standard 62, Indoor Air Quality.* Web site: http://www.ashrae.org.

King County, Washington. *Construction and Landscaping Materials Specifications.* Available online at http://www.metrokc.gov/procure/green/const.htm.

American Society for Testing and Materials (ASTM) Standard D5116-90, Small Scale Environmental Determination of Organic Emissions from Indoor Materials/Products.

U.S. Environmental Protection Agency (EPA). *Tools for Schools Program and Tool Kit.* Available online at http://www.epa.gov/region01/eco/iaq/index.html.

U.S. Environmental Protection Agency (EPA). *Building Air Quality: A Guide for Building Owners and Facility Managers.* Ordering information: Tel: (800) 490-9198, order number EPA402F91102, or view at http://www.epa.gov/iedweb00/base/baqtoc.html.

## References/Additional Information

For additional information about environmentally preferable materials, refer to the Material Selection and Research section in the Introduction to Volume II.

Air Quality Sciences, Inc. *Greenguard Registry.* For more information, see http://www.aqs.com/greenguard.htm or see the article about Greenguard in *Environmental Building News,* Oct 2000, page 5, by Nadav Malin. Greenguard, which lists products that meet widely referenced IAQ guidelines, relies on voluntary emissions standards from government agencies and industry associations.

Architects, Designers and Planners for Social Responsibility (ADPSR) West Coast. 1998. *Architectural Resource Guide.* Contact: ADPSR, PO Box 9126, Berkeley CA. Tel: (510) 273-2428. Resources and information on green and healthy buildings, including many sources for materials in California.

Berkeley Unified School District. 1994. *Materials/Indoor Air Quality Policy* (1994).

California Integrated Waste Management Board (CIWMB) Database of Recycled-Content Providers: http://www.ciwmb.ca.gov/rcp.

Center of Excellence for Sustainable Development, U.S. Department of Energy, Energy Efficiency and Renewable Energy Network (EREN). Provides web pages on green building and green development. Web site: http://www.sustainable.doe.gov.

Hal Levin & Associates. 1999. *Indoor Air Bulletin*. Contact: Hal Levin & Associates, PO Box 8446, Santa Cruz, CA, 95061-8446. Tel: (408) 426-6624. A newsletter for architects and building professionals on indoor air quality.

Los Angeles, City of. *Sustainable Building Reference Manual*. Contact: Nady Maechling. (213) 473-8226. Contains detailed local information and many resources.

Maryland State Department of Education. *Building Ecology & School Design; Technical Bulletin: Carpet and Indoor Air Quality in Schools;* and *Interior Painting and Indoor Air Quality in Schools.* To order, contact the Maryland State Department of Education, Division of Business Services, School Facilities Branch, 200 W. Baltimore St., Baltimore, MD 21201. Phone for Capital Projects Assistant Manager, (410) 767-0097.

National Clearinghouse for Educational Facilities (NCEF). *Managing Indoor Air Quality in Schools.* Available online at http://www.edfacilities.org.

Sorvig, K. 1996. *Sustainable Building Technical Manual.* Washington, DC: Public Technologies Inc. Each chapter offers a concise, valuable overview.

Spiegel, Ross and Dru Meadows. *Green Building Materials, A Guide to Product Selection and Specification.* John Wiley & Sons, Inc. 1999. ISBN 0-471-29133-1.

## Acknowledgments

The following resources were particularly useful for developing this chapter:

Green Building Task Force. The Green Building Task Force was formed by a number of state agencies to institutionalize sustainable building practices into state construction projects. The task force meets on a monthly basis to discuss strategies for implementing sustainable building practices in all future and current state buildings, including those leased by the State. See http://www.ciwmb.ca.gov/greenbuilding/partnerships/default.htm for more information and links to member agencies.

Santa Monica, City of. 1999. *Santa Monica Green Building Design and Construction Guidelines.* Available online at http://greenbuildings.santa-monica.org/main.htm.

Partnership for Resource-Efficient Schools. 1998. *Recommended Best Management Practices Promoting: Energy Efficiency, Resource Conservation, and Environmental Quality.* A publication of the Seattle Public Schools Building Excellence Program and the City of Seattle (Solid Waste Utility, Water Department, and Seattle City Light). The following web site provides information about the Partnership for Resource-Efficient Schools project and a link to download the Best Management Practices manual: http://www.cityofseattle.net/util/rescons/susbuild/partnership.htm.

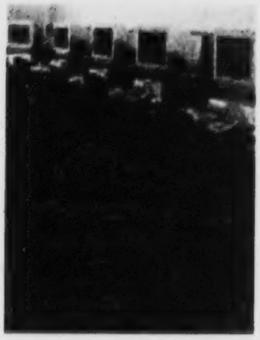
*BUILT GREEN™ Handbook.* 1999. BUILT GREEN™ is a program of the Master Builders Association of King and Snohomish Counties (MBA) in partnership with King County and Snohomish County, Washington. http://www.builtgreen.net/.

Maryland State Department of Education. *Building Ecology & School Design; Technical Bulletin: Carpet and Indoor Air Quality in Schools;* and *Interior Painting and Indoor Air Quality in Schools.* To order, contact the Maryland State Department of Education, Division of Business Services, School Facilities Branch, 200 W. Baltimore St., Baltimore, MD 21201, phone for Capital Projects Assistant Manager, (410) 767-0097.

# Guideline IS1: Carpeting

## Recommendation

Select a carpet, cushion, pad, and adhesives that are non-polluting (low-emissions) and made with recycled content. Where practicable, select a carpet and pad that is recyclable at the end of its life. Follow recommendations from the Carpet and Rug Institute for installation and maintenance.



*Carpeting in a school computer lab. Photo reprinted with permission from the Carpet and Rug Institute, http://www.carpet-rug.com.*

| Applicable Spaces | | Climates | | When to Consider | |
|---|---|---|---|---|---|
| Classrooms | ■ | South Coast | ■ | Programming | ☐ |
| Library | ■ | North Coast | ■ | Schematic | ☐ |
| Mulit-Purpose / Cafeteria | ☐ | Central | ■ | Design Dev. | ■ |
| Gym | ☐ | Mountains | ■ | Contract Docs | ■ |
| Corridors | ☐ | Desert | ■ | Construction | ■ |
| Administration | ■ | | | Commissioning | ☐ |
| Toilets | ☐ | | | Operation | ■ |
| Other | ☐ | | | | |

## Description

Because carpet systems off-gas when new, carpet is a potential source of indoor air pollution. (Typically, most VOCs are emitted from the backing adhesive and seam sealer rather than from the wear layer.) The specifications listed under "Design Details" below provide guidelines for procurement of low-emissions carpeting and adhesives.

## Applicability

Most suitable for classrooms, libraries, and administrative areas.

## Applicable Codes

See "Applicable Codes" in Overview.

## Integrated Design Implications

Flooring type selection affects thermal comfort (carpeting retains heat longer than resilient flooring, for example) and lighting (floor finishes with high reflectivity enhance daylighting). Recycle clean waste carpet, if possible (require subcontractor to take back for recycling).

## Costs

A typical nylon carpet installation costs between $2.20 and $3.00 per square foot. Recycled-content padding and carpeting are priced competitively, with a life expectancy between eight and 12 years.

| Costs | L | M | H |
|---|---|---|---|
| L | ☐ | ■ | ☐ |
| M | ☐ | ☐ | ▨ |
| H | ☐ | ☐ | ☐ |

Benefits

## Benefits

Recycled content/recyclable flooring is materials efficient. Carpeting provides acoustic benefits not available with other flooring types. Emissions specifications for carpeting in schools provides indoor air quality performance guidelines for school environments. Low-toxic adhesives minimize the indoor air pollution load and health risks to both installers and occupants.

## Design Tools

N/A

## Design Details

Note: If regular O&M cannot be assured (due to budget constraints, inadequately trained staff, or other reasons), carpeting should not be used. (See Operations and Maintenance/Owner's Manual discussion below).

### Emissions Criteria

The styrene butadiene latex rubber used to adhere face fibers to backing materials and the adhesives used to install carpets generate volatile organic compounds (VOCs). For these reasons, carpet can be a significant source of indoor air contamination.

A joint effort between the Carpet and Rug Institute (CRI) and the EPA, called the CRI Indoor Air Quality Carpet Testing Program (CRI "Green Label"), identifies carpets that have reduced VOC emissions. However, a Maryland State Department of Education Technical Bulletin, Carpet and Indoor Air Quality in Schools, cautions that CRI certification "does not provide information on comfort and health effects of specific VOC emissions and ... should not be misunderstood to assure a safe product." To achieve improved indoor air quality benefits required for a high performance school, use the specifications provided below, which improve on and update those established by the CRI testing program. (As of the date of this publication, there are at least three major carpet manufacturers of carpets and carpet tiles meeting these specifications[6]):

- Less than 50 micrograms per square meter per hour ($\mu g/M^2$-hr) of formaldehyde.
- Less than 300 $\mu g/M^2$-hr of total volatile organic compounds.
- Less than 400 $\mu g/M^2$-hr of styrene
- Less than 100 $\mu g/M^2$-hr of 4-PC
- Test over a 96-hr time period
- Submit compliance table, which documents the required performance criteria and actual test results

School designers should also require manufacturers to submit the following information for each product making up the carpet system:

- The ingredients, including identification and quantified amounts of substances that are listed on either: (a) the International Agency for Research on Cancer List of Chemical Carcinogens; (b) the Carcinogen List of the National Toxicology Program; or (c) the Reproductive Toxin List of the Catalog of Teratogenic Agents
- Emission factors for VOCs contained in the product, in milligrams per square meter per hour ($mg/M^2$-hr)
- Product TVOC emission factor (e.g., 1, 7, 30 days after manufacture for solid products such as carpet and 1, 4, 24, 48 hours for wet products such as adhesives) ($mg/M^2$-hr)
- Emissions test protocol used
- Organization evaluating the product

### Type of Carpet

When selecting carpet, space classification, desired design life, and desired aesthetics are the traditional considerations.

Look for low pile, dense loop, and needle-punch carpet types trap the least soil and show wear the least. One good choice for schools is a low nap, all-nylon carpet, which is less attractive to dust mites and mold. Also look for recycled-content carpets (see below); the processed materials used in them tend to be less toxic than virgin synthetics. Finally, avoid dark colors; these carpets contain more toxins than light carpets because more dye is needed to create the dark color.

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[6] This performance standard was used by the State of California on the East End Project. For that project, testing information from Interface Flooring Systems of LaGrange, Georgia, Collins & Aikman of Dalton, Georgia, and Milliken of LaGrange, Georgia all demonstrated that their product met or exceed these requirements.

Natural carpets are made form grasses, cotton, and wool, with minimal treatment. However, natural carpet materials can harbor insects and are more difficult to maintain. For these reasons, natural carpet is not recommended for schools.

### Recycled Content

Select a carpet with a minimum of 45% recycled content. Carpet made from 100% recycled terephthalate (PET) plastic from pop bottles is available. While most brands are produced for the residential market, some manufacturers also produce commercial carpet lines. This carpet is generally considered to be more suitable for low- traffic applications (such as private offices) and/or for spaces with shorter design life requirements.

Type One Commercial Carpet is available, either a tile or a broadloom, with backing made with post-consumer plastic (typically nylon, polypropylene or a mix of these two plastics). Some manufacturers offer product lines that contain 50% recycled content plastic by weight and above. Generally commercial carpet made from nylon 6 or 6,6 is the most durable type of carpet. At this writing, at least two manufacturers supply products made with 100% recycled nylon. Many manufacturers will offer a surface wear warranty of 15 years or more (e.g., 10% surface wear by weight). Some carpet manufacturers also offer reclamation programs to facilitate carpet recycling at the end of its useful life (the DuPont Carpet Reclamation Program).

The life expectancy of recycled content carpet is between eight and twelve years.

### Carpet Tiles

Carpet tile systems save money and resources. They generate less waste during installation. They are also easily removed and replaced during renovation, and individual tiles can be easily replaced as needed.

### Refurbished Carpet

At least one manufacturer refurbishes commercial carpet for reapplication as modular carpet tiles. The manufacturer super-cleans, re-textures, and adds new colors and patterns to previously used carpet. The end product has a warranty and costs about half of new. (http://www.earthsquare.com).

### Pad

Specify carpet pad with highest percentage of recycled content (and compatible with selected carpet product). Rubber pad made from recycled tire rubber is a materials efficient choice. It is a dense and durable product with a very long life expectancy. Fibrous pad is also available in commercial grades made from recycled synthetic and natural fiber from textile mill waste.

### Recyclability

Carpet recycling is a priority because of the large volumes being disposed and its resistance to decomposition. Fully recyclable carpets are just newly available. For example, *Powerbond* from Collins and Aikman is 70 percent recycled content by volume and up to 50 percent post-consumer by weight, saving energy and resources in its manufacture. According to the manufacturer, this commercial carpet can outlast standard commercial broadloom carpet by three to five times. The manufacturer will take the carpet back at the end of its useful life and will recycle it back into new carpet backing (i.e., closed loop system).

### Installation

Require suppliers to unroll and air-out carpets in the warehouse before bringing them into the building. Tests indicate that carpet emissions will dissipate within 48 to 72 hours with proper ventilation.

Specify least toxic carpet adhesive system compatible with selected carpet product. Require installer to use the smallest amount of adhesive necessary to fulfill the manufacturer's performance specifications for that product. Alternately, specify tack-down carpet to eliminate gluing.

Air out space(s) where carpet has been installed for a minimum of 72 hours. With a central HVAC system, the ventilation supply should be on, the return grille(s) sealed, and windows open.

In renovations, carpet installation should occur only when the school building is not in use. An exception would be for small installations in which the space can be exhausted directly to the outdoors causing the room to be under negative pressure. Ventilation should continue for a minimum of 72 hours after installation.

Do not install carpet near water fountains, sinks, showers, pools, or other locations where it may get wet.

Note: If covering a large surface area, carpet and other fabrics can act as "sinks" for the absorption of VOCs from other sources (during application of paint and other finish coatings, for example) and re-emit them later. To minimize this "sink" effect and subsequent extended re-emitting of VOCs, install soft surfaces as late as possible and/or remove or cover all soft surfaces and use direct ventilation until the offensive coating dries.

### Operation and Maintenance / Owner's Manual

Carpeting acts as a highly effective reservoir for allergens such as dirt, pollen, mold spores, dust mites, and other toxins, which are everywhere present outdoors and often introduced into the indoor environment in dirt from occupants' shoes. Old carpeting may pose more health risks to its occupants than new. Microbial contamination resulting from water infiltration or inadequate cleaning procedures is a frequent problem. Fungi and dust mites are two contaminants that can trigger allergies or cause illness in a significant number of people. To help ensure longer life, maintain appearance, and help protect indoor air quality, carpet requires regular vacuuming with a well-functioning vacuum cleaner equipped with strong suction and a high filtration bag.

Spills must be cleaned up immediately and thoroughly. If carpet becomes saturated and water is not quickly removed (less than 24 hours), experience suggests that in most situations, carpeting will have to be discarded.

### Commissioning

Airing out the space during and after carpet installation is essential and is recommended by the Carpet and Rug Institute, the U.S. Environmental Protection Agency, and the U.S. Consumer Product Safety Commission. The typical recommendation is to continuously operate the building ventilation system at normal temperature and maximum outdoor air during installation and for 72 hours after installation is completed. The CRI *Standard for Installation of Commercial Textile Floor Covering Materials* (CRI 104) addresses the topic of airing and other installation procedures.

### Example(s)

Cold Spring Elementary School—used recyclable carpet as part of the Collins & Aikman carpet recycling program.

*Earth Square* by Milliken is installed at:

The Woodward Academy in Atlanta, GA, the largest private K – 12 in the country. Five projects have now been installed on campus. Earth Square is now a standard for use based on environmental and economical reasons.

The LaGrange Academy in LaGrange, GA. Several projects installed at this K – 12 campus, including a multi-purpose building.

## References/Additional Information

*Standard for Installation of Commercial Carpet,* CRI 104. An industry minimum commercial installation standard published by the Carpet and Rug Institute (CRI). Contains detailed outlines of technique, procedure, and terminology used in specification writing, planning, layout, and installation. Includes accepted tools and materials, floor preparation, installation in special areas, diagrams and charts. 25 pages, 8 ½" x 11" $6.00 each. ISBN #0-89275-010-3. To order, call CRI at 800-882--8846.

*Carpet and Indoor Air Quality in Schools.* Published by the School Facility Branch of the Maryland State Department of Education. To order, contact the Maryland State Department of Education, Division of Business Services, School Facilities Branch, 200 W. Baltimore St., Baltimore, MD 21201, phone for Capital Projects Assistant Manager, (410)-767-0097.

The web site of the Carpet and Rug Institute (CRI), http://www.carpet-rug.com. Provides information on selection, installation, and maintenance.

*Carpet and Indoor Air Quality in Schools.* Technical Bulletin. 1993. A publication of the Maryland State Department of Education. To order, contact the Maryland State Department of Education, Division of Business Services, School Facilities Branch, 200 W. Baltimore St., Baltimore, MD 21201. Phone for Capital Projects Assistant Manager: (410) 767-0097.

California Integrated Waste Management Board (CIWMB) Database of Recycled-Content Providers: http://www.ciwmb.ca.gov/rcp.

*Comprehensive Procurement Guidelines.* The recommended recovered material content for polyester face carpet fiber is listed as 25-100% PET resin (recycled plastic soda bottles). Envirotech (Image) and Envirolon (Talisman) lines meet this standard. EPA is expanding it's definition of environmentally preferred carpet by including nylon fiber with recycled-content backing (i.e., Collins and Aikman, Shaw, Interface). These new standards will soon be reflected in the CPGs. For more information on carpet manufacturers and suppliers and a GSA link, visit EPA's web site: http://www.epa.gov/epaoswer/non-hw/procure/products/carpet.htm.

*Environmentally Responsible Carpet Choices,* Sustainable Practices and Opportunities Plan, a project of the Department of Interior, National Park Services. http://www.nps.gov/sustain/spop/carpet.htm

# Guideline IS2: Resilient Flooring

## Recommendation

Select resilient flooring and adhesives that are materials-efficient and non-polluting.

## Description

Although vinyl composition tile (VCT) has been the finish of choice for uncarpeted areas in schools, vinyl flooring should be avoided in a high performance school. VCT is made of non-renewable resources and there is concern about environmental degradation associated with its production.

Environmentally preferred resilient flooring types include natural linoleum, chlorine-free resilient flooring, and recycled rubber tile/sheet. With respect to materials efficiency and air quality, there are important distinctions between material types, installation methods, and maintenance requirements. Final selection will depend upon the application and cost constraints.

*"Linorette" linoleum from Armstrong. Photo reprinted with permission.* http://www.armstrong.com/commflooringna/

| Applicable Spaces | |
|---|---|
| Classrooms | ▨ |
| Library | ▨ |
| Mulit-Purpose / Cafeteria | ■ |
| Gym | ☐ |
| Corridors | ■ |
| Administration | ▨ |
| Toilets | ■ |
| Other | ■ |

| Climates | |
|---|---|
| South Coast | ■ |
| North Coast | ■ |
| Central | ■ |
| Mountains | ■ |
| Desert | ■ |

| When to Consider | |
|---|---|
| Programming | ☐ |
| Schematic | ☐ |
| Design Dev | ■ |
| Contract Docs | ■ |
| Construction | ■ |
| Commissioning | ☐ |
| Operation | ■ |

## Applicability

Most suitable for high traffic areas not requiring the acoustic benefits of carpet, such as hallways, cafeterias, and toilets.

Linoleum has a mild antiseptic effect that reduces sour odors from urine and food spills, so is a good choice for kitchens, cafeterias, and washrooms.

## Applicable Codes

See "Applicable Codes" in Overview.

## Integrated Design Implications

Flooring type selection affects thermal comfort (carpeting retains heat longer than resilient flooring, for example) and lighting (floor finishes with high reflectivity enhance daylighting). Resilient flooring does not generally provide the acoustic benefits of carpeting. Teacher preferences should also be considered, if feasible. Recycle waste flooring, if possible (require subcontractor to take back for recycling).

## Costs

Will vary with type chosen. Linoleum costs more than VCT but is competitive with higher-quality grades of sheet vinyl. Installed costs typically range from $3.50 to $3.75 per square foot. If properly installed and maintained, linoleum should last at least 30 to 40 years—and it actually gets stronger with age as the linseed oil oxidizes.

| Costs | L | M | H |
|---|---|---|---|
| L | ■ | | |
| M | | | ▨ |
| H | | | |
| | **Benefits** | | |

Solenium from Interface costs about $3 per ft$^2$ installed. This price includes training on maintenance issues, and take-back of the product at the end of its service life.

Other alternatives, including cork and Amtico Stratica are more expensive.

## Benefits

Use of alternatives to VCT flooring is ecosystem-protective, avoiding environmental degradation attributed to the mining of limestone and production of PVC, which are both used in the manufacture of VCT.

Recycled content/recyclable flooring is materials efficient.

True linoleum is made with renewable materials (linseed oil, cork, wood dust and jute), contains none of the petrochemicals and chlorine found in vinyl and VCT flooring or the plasticizers found in vinyl sheet flooring. All of its ingredients are minimally processed, commonly available, and biodegradable. Linoleum is extremely durable. If incinerated at the end of its useful life, the products of combustion are relatively inert.

Low-toxic adhesives and coatings minimize the indoor air pollution load and health risks to both installers and occupants.

## Design Tools

See Overview, above.

## Design Details

All resilient flooring products produce some air pollutant emissions; so do their setting and maintenance products. Ask for manufacturer's emissions data to will aid in selection.

Consider environmentally preferable, vinyl-free resilient flooring, such *Stratica* flooring tiles from Amtico International, Inc. of Atlanta, Georgia, which is made from chlorine-free, mineral filled ethylene co-polymer backing (instead of vinyl). Although manufactured from refined petrochemicals, the product is efficiently manufactured (Amtico is certified under the ISO Standard 14001 for environmental performance), low emissions, highly durable, and recyclable.

Natural linoleum is another chlorine-free, environmentally preferable product, made out of nearly all natural ingredients. At present, linoleum is produced only in Europe at only three companies: Forbo Industries in the Netherlands, DLW Linoleum in Germany, and Linosom Linoleum in France.

Note: Linoleum emits a fairly strong smell when the flooring is newly installed. The smell comes from linseed oil's oxidation products, which are primarily fatty acids—compounds that have a strong smell even at very low concentrations.

*Solenium* from Interface is a "resilient textile flooring," which comes in 1 $m^2$ (39"x39") tiles, comprising a sandwich of very different materials that is designed to come apart for recycling. Developed as part of the company's sustainability initiative, Solenium is recyclable, durable and manufactured using renewable energy. Acoustically it performs like carpet, according to the company. Interface has targeted schools and hospitals as its primary markets for Solenium, because both environments benefit from the comfort and acoustic qualities of carpet but struggle with the maintenance and cleanliness issues.

Cork is a natural material and harvested from trees in a sustainable manner. Cork flooring is durable, fairly easy to clean, sound absorbing, thermally insulating, and naturally moisture-, mold-, and rot-resistant. Drawbacks are its high cost and high embodied energy (because it is imported and is energy-intensive to ship to North America). Also, some flooring manufacturers use toxic materials as binders and in installation. Request and carefully review manufacturer's documentation for composition of binders, adhesives, and coatings.

Recycled rubber tile and sheet goods are also available made with waste tires. These are materials efficient choices for heavy traffic and utility areas, but may be VOC emitters.

Require installer to use the smallest amount of adhesive necessary to fulfill the manufacturer's performance specifications for that product. (Note: In some applications, interlocked rubber tiles and heavy linoleum can be laid without adhesive.)

Specify adequate ventilation during installation and flush out the building for a minimum of 72 hours after installation.

### Operation and Maintenance Issues

Maintenance products are also significant pollution sources. Flooring with sealed "low maintenance" surfaces should be preferred, both for reducing maintenance costs and the use of cleaners and waxes. Low VOC cleaners and sealers are available. Be sure to consult with the manufacturer when specifying sealers and other maintenance products. Use of the wrong products can cause problems, especially with natural linoleum. To help ensure longer life, maintain appearance, and help protect indoor air quality, resilient require cleaning/ vacuuming.

### Commissioning

N/A

### Example(s)

### References/Additional Information

See resources listed in Overview.

Also see the following articles from *Environmental Building News*:

"A New Chlorine-free Competitor to Vinyl Flooring," Volume 7, No. 10, November 1998. (About Amtico *Stratica flooring)*.

"Solenium—The First Resilient Textile Flooring," Volume 8, Number 5, May 1999.

"Cork Flooring," Volume 5, No. 1, January/February 1996.

# Guideline IS3: Ceramic Tile / Terrazzo

**Recommendation**

Select locally available, recycled content ceramic or clay tile. If installing terrazzo, avoid the epoxy type; substitute cementitious terrazzo, where appropriate. Specify low-toxic adhesives, grouts, caulks, sealants, and setting materials.

**Description**

Ceramics, clay tiles, and terrazzo (made with cement and crushed stone) are durable and low emission interior finishes.

Terrazzo is a family of flooring materials that incorporates natural marble chips and other aggregates in a cementitious or epoxy mixture, which is usually applied wet and allowed to cure in place.

**Applicability**

Most suitable for traffic areas requiring high durability and low maintenance, but not requiring the acoustic benefits of carpet, such as entryways and toilets.

**Applicable Codes**

See "Applicable Codes" in Overview.

*TerraTraffic from Terra Green Ceramics is made in the USA from over 55% recycled glass and select ceramic materials. Photo reprinted with permission from Terra Green Ceramics. http://www.terragreenceramics.com.*

| Applicable Spaces | |
|---|---|
| Classrooms | ☐ |
| Library | ☐ |
| Mulit-Purpose / Cafeteria | ☐ |
| Gym | ☐ |
| Corridors | ☐ |
| Administration | ☐ |
| Toilets | ■ |
| Other | ■ |

| Climates | |
|---|---|
| South Coast | ■ |
| North Coast | ■ |
| Central | ■ |
| Mountains | ■ |
| Desert | ■ |

| When to Consider | |
|---|---|
| Programming | ☐ |
| Schematic | ☐ |
| Design Dev. | ■ |
| Contract Docs | ■ |
| Construction | ■ |
| Commissioning | ☐ |
| Operation | ■ |

**Integrated Design Implications**

Flooring type selection affects thermal comfort (carpeting retains heat longer than resilient flooring, for example) and lighting (floor finishes with high reflectivity enhance daylighting). Tile/terrazzo flooring does not provide the acoustic benefits of carpeting, so this, along with teacher preferences, should be considered. Recycle waste tile if possible (require subcontractor to take back for recycling).

**Costs**

Terrazzo costs between $5.00 and $10.00 per square foot to install and will last the life of the building. Ceramic tile costs between $6.00 and $12.00 per square foot installed and will last 40 to 80 years. Recycled-content tile is higher priced than average tile products. Low maintenance costs. Least toxic adhesives used with tile and terrazzo are generally locally available at competitive costs.

| Costs | L | M | H |
|---|---|---|---|
| L | ■ | | |
| M | | | ▨ |
| H | | | |

Benefits

**Benefits**

Use of local or regionally manufactured ceramics reduces the high transportation consumption/cost associated importing with this heavy building material. Ceramics and terrazzo (made with cement and crushed stone) are durable and low emissions. Some tile is available with recycled content (up to 70%), such as scrap glass and feldspar waste from mining, which is materials efficient. Some manufacturers also have added heat recovery, water recovery, and clay mine restoration measures to their operations that exceed industry norms, which is ecosystem-protective.

Low-toxic adhesives and coatings minimize the indoor pollution load and health risks to both installers and occupants.

## Cost Effectiveness

Though costly to purchase and install, ceramic tile / terrazzo *life cycle* cost is among the lowest of all finishes for some applications, due to its long life and minimal maintenance. Ceramic tile with recycled content can cost 1.5 to 2 times more than conventional.

## Design Tools

See Overview, above.

## Design Details

Tile is a packaging-intensive product. Specify recyclable packaging.

### Terrazzo

The two types of binders used in terrazzo flooring raise different environmental issues during installation. Cementitious terrazzo is composed of inert ingredients mixed with water. The primary installation hazard is dust during mixing and grinding. The installation of epoxy terrazzo, however, requires the use of OSHA-approved respirators, protective gloves, and safety glasses, as well as ventilation with 100% fresh air. The epoxy matrix contains a number of toxic materials. For these reasons, use of the epoxy type terrazzo should be avoided.

### Tile

Avoid the use of imported tile. The glazing used on imported tiles can contain lead and imported tiles have high embodied energy.

Mortar, Adhesives, Caulking, and Sealants—Cement mortars, usually modified with acrylic additives, are the safest to handle for tile setting and offer the best performance for most applications. All plastic adhesives contain some solvents and will contribute to indoor air pollution. Where adhesives and caulking must be used, such as for cove bases and flexible joints, choose a low solvent-content product such as an acrylic. Cement-based, cellulose-based and acrylic-modified grouts are safe and low emission. Glazed tile and high-fired tile usually do not require sealers. If a porous tile is chosen, the safest sealers are the low-volatile, acrylic or water-based silicone types. Check with the tile manufacturer to select the lowest VOC, least toxic mortars, sealers, caulks, and adhesives that will provide the desired performance.

### Installation

Specify adequate ventilation during installation.

Require installer to use the smallest amount of adhesive and sealant necessary to fulfill the manufacturer's performance specifications for that product.

## Operation and Maintenance Issues

Terrazzo flooring must be sealed to prevent absorption of dirt and stains. Water-based sealers are available. Maintenance for ceramic tile varies with the type of surface and grout. Most unglazed tile is sealed after installation.

## Commissioning

N/A

### Example(s)

### References/Additional Information

See references listed in Overview.

# Guideline IS4: Concrete Flooring

### Recommendation

Select concrete flooring, made with flyash. Use least toxic adhesives, sealers, and wax.

### Description

Finished concrete flooring is an integral system of slab and finish, produced by adding colorants and a sealer to the topping concrete (colorized cement) either before or after it cures. The concrete is often stamped with tile patterns and grid lines that also control cracking.

Applying a colorized stain to a cured concrete surface produces stained concrete flooring.

Both types of concrete flooring provide a durable and low maintenance finish. Saw-cut and other designs and colors can add interest and educational value.

*Installation of **finished concrete flooring**. Photo reprinted with permission from Davis Colors, Inc.*
http://www.daviscolors.com

| **Applicable Spaces** | | **Climates** | | **When to Consider** | |
|---|---|---|---|---|---|
| Classrooms | ☐ | South Coast | ■ | Programming | ☐ |
| Library | ☐ | North Coast | ■ | Schematic | ☐ |
| Mulit-Purpose / Cafeteria | ▨ | Central | ■ | Design Dev | ■ |
| Gym | ☐ | Mountains | ■ | Contract Docs | ■ |
| Corridors | ■ | Desert | ■ | Construction | ■ |
| Administration | ☐ | | | Commissioning | ☐ |
| Toilets | ▨ | | | Operation | ■ |
| Other | ▨ | | | | |

### Applicability

Especially suitable for high traffic areas, such as hallways, cafeterias, and gathering areas. Staining existing concrete flooring is generally appropriate for renovation. Finished concrete flooring with integral colorants is generally applicable to new installations.

### Applicable Codes

See "Applicable Codes" in Overview.

### Integrated Design Implications

Flooring type selection affects thermal comfort (carpeting retains heat longer than resilient flooring, for example) and lighting (floor finishes with high reflectivity enhance daylighting). Concrete flooring adds thermal mass.

### Costs

Medium ($3.00 per square foot) to high first cost, depending upon complexity of the installation/design.

| Costs | L | M | H |
|---|---|---|---|
| L | ■ | ▨ | ☐ |
| M | ☐ | ☐ | ☐ |
| H | ☐ | ☐ | ☐ |

Benefits

### Benefits

Concrete flooring is highly durable and low maintenance, conserving materials and potential indoor air quality problems due to maintenance products. Concrete with flyash is materials efficient. Low-toxic coatings minimize the indoor air pollution load and health risks to both installers and occupants.

### Design Tools

See Design Tools listed in Overview.

## Design Details

### Selection

Finished systems with integral color added to the entire topping layer are more resistant to damage, and less likely to require re-coloring (a potential source of indoor air pollution) than systems that are dyed after placing the concrete.

Ask supplier to recommend least toxic, VOC-compliant sealers and wax that will fulfill performance requirements.

Concrete staining is a technique often used in renovation of existing buildings with existing concrete sub-floors.

A variety of techniques are available to add designs—for example, cultural, school, community symbols—for use as teaching tools. Such artistic/educational amenities, however, will increase the cost.

### Installation

Specify adequate ventilation during installation and flush out the building in accordance to project specifications.

Require installer to use the smallest amount of sealers and wax necessary to fulfill the manufacturer's performance specifications for that product.

## Operation and Maintenance Issues

Proper sealing and re-waxing of stained concrete floors will ensure a long service life. Stained concrete flooring requires periodic re-waxing.

## Commissioning

N/A

## Example(s)

Lick Wilmerding High School, San Francisco, CA—stained concrete flooring in the corridors of a new library.

Ross Middle School, Ross, CA (Marin County)—Installed stained concrete floors, eliminating all carpet, resilient flooring, and related adhesives. Used low VOC sealers.

## References/Additional Information

See references listed in Overview.

# Guideline IS5: Wood Flooring

## Recommendation

Select environmentally preferable products for wood flooring. Specify low toxic adhesives, sealers, and finishes.

## Description

Environmentally preferable wood flooring types include certified hardwood, salvaged wood, and laminated or veneered wood products.

If using hardwood, specify products certified by the Forest Stewardship Council (FSC). Other environmentally preferable alternatives to conventional hardwood flooring include a wide range of veneered and laminated products that have a hardwood surface with a plywood or MDF core

*Trademark reproduced with permission. FSC Trademark © 1998 Forest Stewardship Council A.C.*

| **Applicable Spaces** | |
|---|---|
| Classrooms | ▨ |
| Library | ☐ |
| Mulit-Purpose / Cafeteria | ▨ |
| Gym | ■ |
| Corridors | ☐ |
| Administration | ☐ |
| Toilets | ☐ |
| Other | ▨ |

| | **Climates** |
|---|---|
| ■ | South Coast |
| ■ | North Coast |
| ■ | Central |
| ■ | Mountains |
| ■ | Desert |

| **When to Consider** | |
|---|---|
| Programming | ☐ |
| Schematic | ☐ |
| Design Dev. | ■ |
| Contract Docs | ■ |
| Construction | ■ |
| Commissioning | ☐ |
| Operation | ■ |

## Applicability

Wood flooring is typically now specified for schools only where its performance characteristics make it uniquely desirable: gymnasiums, stages, and dance studios. However, some studies suggest that wood flooring from sustainable forests may be an appropriate flooring material for more functions, including classrooms, especially in regions where desirable species are native.

## Applicable Codes

See "Applicable Codes" in Overview.

## Integrated Design Implications

Flooring type selection affects thermal comfort (carpeting retains heat longer than resilient flooring, for example) and lighting (floor finishes with higher reflectivity enhance daylighting).

## Costs

Wood flooring costs between $6.00 and $10.00 per square foot. Its life expectancy averages 38 years. There is a cost premium for certified wood, ranging from modest to significant, depending upon quantity, type, and current availability.

| Costs | L | M | H |
|---|---|---|---|
| L | ■ | ☐ | ☐ |
| M | ☐ | ☐ | ☐ |
| H | ☐ | ☐ | ▨ |
| | **Benefits** | | |

## Benefits

FSC-certified wood is eco-system protective. Low-toxic adhesives and coatings minimize the indoor air pollution load and health risks to both installers and occupants. The factory pre-finished products have substantial air quality benefits because no sanding and finishing is done on site.

## Design Tools

Design Tools listed in Overview, above, and:

*Certified Forest Products Database*, Certified Forest Products Council. Web site: http://www.certifiedwood.org. Contact: 14780 SW Osprey Dr., Suite 285, Beaverton, OR 97007. Tel: (503) 590-6600. Industry information on suppliers and standards.

## Design Details

### Selection

Several FSC-certified hardwood flooring products are available. Look for woods grown in regional forests, which reduces the energy consumption involved in transportation. Woods common to the western area include pine, aspen, spruce, fir, and hemlock.

Veneered and laminated products that have a plywood or MDF core are also environmentally preferable choices, but are less repairable than solid wood. These are usually pre-finished at the factory with a very durable, low-maintenance finish.

Low-toxic, clear sealers are also available to use as finishes for woodwork. Water-based varnishes, polyurethane, and other finishes for hardwood floors are very durable and much safer to handle than traditional products. Low-toxic solvents, water-based strippers, and all-natural thinners are also locally available.

### Handling

Specify that woodwork be protected from water damage during transit, delivery, storage, and handling (in addition to saving materials, this helps prevent future moisture/IAQ problems).

### Installation

A steel track system using wedges to hold the flooring in place, or a "floating system," using edge gluing where necessary makes wood floors easy to remove. A nail down system is also salvageable, but with some loss of material. Avoid parquet systems, which require a glue down system and are therefore the least salvageable.

If sanding is done on the premises, the area must be carefully isolated, including sealing off the doors and HVAC system, and using temporary fans. Specify final cleanup with a HEPA filter-equipped vacuum.

Require installer to use the smallest amount of adhesive/coating necessary to fulfill the manufacturer's performance specifications for that product.

For finishing on site, water-based urethanes (urethane/ acrylic blends), with low-volatile content have the least emissions of common finishes. Hardening oils, solvent varnishes and acid cured varnishes have prolonged emissions. If edge gluing is required, specify a low toxicity product such as white carpenters or woodworkers glue. If glue-down methods are required, such as for parquet, specify a low-volatile flooring adhesive.

Specify adequate ventilation during installation.

Note: Woods naturally emit formaldehyde, but in minute amounts.

## Operation and Maintenance Issues

After finished with a synthetic topcoat, maintenance requirements for wood floors are similar to VCT and terrazzo. A typical hardwood floor might need re-sanding (which generates airborne dust) every eight to ten years and can be re-sanded up to five times. Annual screening and re-coating maintains the protective wear layers. Wood flooring is easier to repair than most other materials.

## Commissioning

N/A

## Example(s

## References/Additional Information

See references listed in Overview, above.

For general information on certified lumber, contact: Certified Forest Stewardship Council, Jeff Wartelle. Tel: (503) 590-6600. Industry group provides information on distribution and other assistance.

*Certified Forest Products Database,* Certified Forest Products Council, http://www.certifiedwood.org. Contact: 14780 SW Osprey Dr., Suite 285, Beaverton, OR 97007. Tel: (503) 590-6600. Industry information on suppliers and standards.

Two private companies in the U.S. are authorized to issue the FSC stamp of approval: Scientific Certification Systems (SCS) in Oakland, CA (http://www.scs1.com/forestry1.shtml), and SmartWood Certified Forestry, based in Richmond, VT, with an affiliate in Oregon (http://www.isf-sw.org/cert.htm).

# Guideline IS6: Bamboo Flooring

## Recommendation

Specify domestically-produced flooring made from rapidly renewable bamboo. Install/finish with a low toxic, water-based sealer and wax.

## Description

Bamboo is a natural material and renewable resource. Most bamboo used in flooring production is grown in and imported from China. Bamboo flooring is harder than most common wood flooring, very durable, and dimensionally stable.

## Applicability

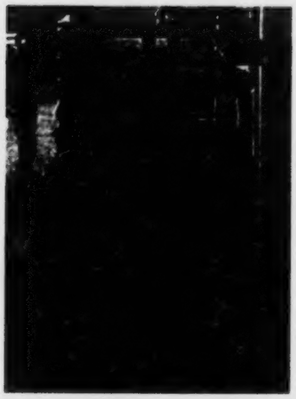
Suitable wherever wood flooring would be used.

## Applicable Codes

See "Applicable Codes" in Overview.

## Integrated Design Implications

Flooring type selection affects thermal comfort (carpeting retains heat longer than other flooring does, for example) and lighting (floor finishes with high reflectivity enhance daylighting).



*Bamboo flooring in a residence, copyright TimberGrass LLC. Photo by Art Grice. Photo reprrinted with permission from TimberGrass, LLC. http://www.timbergrass.com*

| Applicable Spaces | | Climates | | When to Consider | |
|---|---|---|---|---|---|
| Classrooms | ☐ | South Coast | ■ | Programming | ☐ |
| Library | ■ | North Coast | ■ | Schematic | ☐ |
| Mulit-Purpose / Cafeteria | ■ | Central | ■ | Design Dev | ■ |
| Gym | ■ | Mountains | ■ | Contract Docs | ■ |
| Corridors | ■ | Desert | ■ | Construction | ■ |
| Administration | ■ | | | Commissioning | ☐ |
| Toilets | ☐ | | | Operation | ■ |
| Other | ☐ | | | | |

## Costs

From $4 to $8 per square foot, which is slightly more than domestic hardwoods. However, bamboo is more durable than wood, (25% harder than oak and 12% harder than maple, according to one manufacturer).

| Costs | L | M | H |
|---|---|---|---|
| L | ■ | | |
| M | | | |
| H | | | ▨ |

Benefits

## Benefits

Bamboo flooring is aesthetically pleasing, low-emitting, durable, and produced from a renewable, harvested resource. It is 25% harder than oak, 12% harder than maple and 2.5 times more dimensionally stable than maple. Low-toxic adhesives and coatings minimize the indoor air pollution load and health risks to both installers and occupants.

## Design Tools

Listed in Overview, above.

## Design Details

Specify use of adequate ventilation during installation.

## Operation and Maintenance Issues

Similar to conventional hardwood flooring.

### Commissioning

N/A

### Example(s)

### References/Additional Information

References listed in Overview, above.

The American Bamboo Society. Web site: http://www.bamboo.org/abs.

West Coast suppliers include:

Timbergrass, LLC, 9790 NE Murden Cove Drive, Bainbridge Island, (206) 842-9477 or (800) 929-6333. Email info@timbergrass.com or web site http://www.timbergrass.com.

Bamboo Hardwoods, 3834 4th Ave. South, Seattle, (206) 264-2414. Web site: http://www.bamboohardwoods.com.

Smith & Fong Company, San Francisco, CA., Web site: http://www.plyboo.com.

Bamboo Hardwoods Mfg. Co, Seattle, WA. Web site: http://www.bamboohardwoods.com/.

Bamboo Flooring International Corp., Walnut, CA. Web site: http://www.bamboo-flooring.com/.

# Guideline IS7: Gypsum Board

### Recommendation

Specify gypsum wallboard with a minimum of 10% recycled content gypsum and 100% recycled content paper facing or gypsum produced by the fibergypsum process.

### Description

Gypsum products are the most common interior panels used due to their fire retardant characteristics and low cost. Recycled content products are available at no cost premium (but must be specified).

### Applicability

Suitable for all spaces. High impact gypsum is appropriate for spaces requiring higher than normal durability.

### Applicable Codes

See "Applicable Codes" in Overview

### Integrated Design Implications

Wallboard installation should be coordinated with the job-site waste reduction plan. Recycle clean waste drywall (require subcontractor to take back for recycling).

### Costs

Least cost option for walls; competitively priced with drop-in ceiling systems for ceilings.

*Photo courtesy of O'Brien & Company, Inc.*

| Applicable Spaces | | Climates | | When to Consider | |
|---|---|---|---|---|---|
| Classrooms | ■ | South Coast | ■ | Programming | □ |
| Library | ■ | North Coast | ■ | Schematic | □ |
| Mulit-Purpose / Cafeteria | ■ | Central | ■ | Design Dev | ■ |
| Gym | ■ | Mountains | ■ | Contract Docs | ■ |
| Corridors | ■ | Desert | ■ | Construction | ■ |
| Administration | ■ | | | Commissioning | □ |
| Toilets | ■ | | | Operation | ■ |
| Other | ■ | | | | |

### Benefits

Gypsum is highly recyclable if not contaminated (with paint or adhesives) and the paper facing can be made with recycled paper. Use of recycled content gypsum is materials efficient at no cost premium. High impact gypsum is more durable than conventional wallboard and has higher recycled content.

| Costs | L | M | H |
|---|---|---|---|
| L | ■ | ▨ | □ |
| M | □ | □ | □ |
| H | □ | □ | □ |
| | **Benefits** | | |

### Design Tools

Listed in Overview, above.

*Designing with Vision: A Technical Manual for Material Choices in Sustainable Construction.* Revised July 2000. A publication of the California Integrated Waste Management Board. See Chapter 8, "Strategies to Reuse Materials and Reduce Material Use in Construction," Appendix F sample specifications for: Section 09250 Gypsum Board. *Designing with Vision* can be downloaded in four parts from http://www.ciwmb.ca.gov/GreenBuilding/. Chapter 8 is in Part D.

## Design Details

### Selection

Specify minimum 10% recycled content. (There is no cost premium for recycled content gypsum, but must be specified, since recycled content is not automatically provided.)

Consider gypsum produced by a recent innovation, the fibergypsum process. This board, now available in the US, has no paper facing but contains recycled wood, paper fiber and perlite. It is very strong and scratch-resistant, and appropriate for high wear areas such as schools.

*Fiberbond* from Louisiana Pacific Corporation is a high impact gypsum board containing up to 15 percent post-consumer cellulose from newsprint, gypsum, and perlite. This product is more durable than conventional wallboard.

### Installation

Specify wet sanding processes during finishing. (Exception: Dry sanding may be allowed subject to full isolation of the affected space(s), installation of protective plastic sheeting to provide air sealing during the sanding; closure of all air system devices and ductwork, sequencing of construction to prevent contaminating other spaces with gypsum dust, use of proper worker protection, Owner approval of these measures.)

Unpainted gypsum surfaces are potent "sinks"— they absorb odors and then re-emit them. Require adequate ventilation during installation of adhesives and other materials that emit indoor pollutants. Where feasible, sequence work to avoid exposing applying VOC-containing materials in spaces with exposed, unpainted gypsum surfaces.

Immediately remove from the site any wetted gypsum boards to eliminate mold contamination.

"The Nailer" is a wallboard installation hardware product made by The Millenium Group, Inc. of Estes Park, CO ((800) 280-2304) that replaces wood backing used in traditional gypsum board installation. Besides saving wood, the product is materials efficient (Contains 25 percent post-consumer plastic and 75 percent post-industrial waste) and labor-saving.

## Operation and Maintenance Issues

Requires periodic painting for aesthetic purposes. Type of paint determines cleanability. Wallboard is easy to repair.

## Commissioning

N/A

## Example(s)

Ross Middle School, Ross, CA (Marin County)—Used recycled content gypsum board.

## References/Additional Information

See the Overview, above.

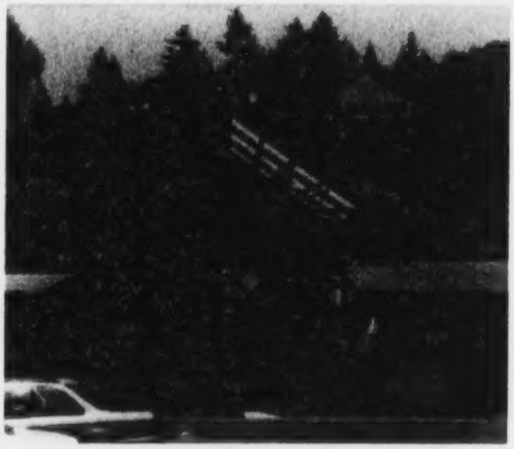
# Guideline IS8: Concrete Masonry

## Recommendation

Specify colored concrete masonry for CMU wall applications.

## Description

CMU construction is high-strength, fire-resistant, durable, and economical. Improvements in manufacturing and quality control of colored concrete masonry assure greater CMU uniformity and color consistency, reduced porosity, and reduced shrinkage. In addition, high-performance water repellents can be applied to walls or added to the concrete and mortar mixes so that it is unnecessary to paint or coat the units with block-filler to avoid water penetration.



*CMU Construction at the Central Market, Poulsbo, Washington. Photo courtesy of O'Brien and Co. Inc.*

## Applicability

| Applicable Spaces | |
|---|---|
| Classrooms | ■ |
| Library | ■ |
| Mulit-Purpose / Cafeteria | ■ |
| Gym | ■ |
| Corridors | ■ |
| Administration | ■ |
| Toilets | ■ |
| Other | ■ |

| Climates | |
|---|---|
| South Coast | ■ |
| North Coast | ■ |
| Central | ■ |
| Mountains | ■ |
| Desert | ■ |

| When to Consider | |
|---|---|
| Programming | □ |
| Schematic | □ |
| Design Dev | ■ |
| Contract Docs | ■ |
| Construction | ■ |
| Commissioning | □ |
| Operation | ■ |

### Applicable Codes

See "Applicable Codes" in Overview, and:

American Concrete Institute ACI 530, *Building Code Requirements for Masonry Structures.* The 1999 Building Code Requirements for Masonry Structures, Specifications for Masonry Structures and Related Commentaries. Will be referenced by the International Building Code (IBC 2000) for the design and construction of masonry structures. This publication is a joint effort of the American Concrete Institute, the American Society of Civil Engineers, and The Masonry Society.

American Concrete Institute ACI's 318-99, *Building Code Requirements for Structural Concrete and Commentary.* Provides engineers, designers, contractors, and other professionals with the latest design and construction requirements. Will be referenced by IBC 2000

## Integrated Design Implications

Recycle waste CMU's, if possible (require supplier/subcontractor to take back for recycling).

## Costs

The first cost of masonry walls is considerably more than for traditional, framed walls. In cold climates, masonry walls exposed to the exterior must be insulated, entailing additional cost in materials and labor. However, not having to paint or coat a colored CMU wall saves time and money during construction, and additional savings accrue throughout the lifetime of the building since colored concrete is a permanent material that requires little or no maintenance.

| Costs \ Benefits | L | M | H |
|---|---|---|---|
| L | □ | ■ | ▨ |
| M | □ | □ | □ |
| H | □ | □ | □ |

### Benefits

Masonry is a materials-efficient, high strength, highly durable material with high fire resistance and low maintenance requirements. The integral color pigments typically used in colored CMU are nontoxic and contain none of the solvents associated with painting and re-painting.

### Design Tools

See Design Tools listed in Overview, above, and:

American Concrete Institute ACI 530.1, *Specifications for Masonry Structures*

ASTM C90, *Specification for Loadbearing Concrete Masonry Units*

ASTM C270, *Specification for Mortar for Unit Masonry*

ASTM C979, *Pigments for Integrally Colored Concrete*

### Design Details

In general, colored CMU is specified and installed in the same way as other high-quality masonry construction.

To assure uniform colors, all CMU used on a particular project should be produced with consistent manufacturing and curing techniques and with cement and aggregates from a single source. Pigments should comply with ASTM C979 Pigments for Integrally Colored Concrete, which establishes criteria for the pigment's resistance to weather and light and its compatibility with concrete. Mortar can be tinted with the same pigments used in the CMU to match or complement the hue of the masonry units. Some variation in appearance is a normal design feature of CMU and mortar, whether colored or not. Mortar lightens as it cures; allow up to 28 days for this process.

Specify the submittal of samples showing the range of each CMU to be used on the job. On jobs with critical appearance tolerances or unique requirements, specify a mock-up to demonstrate that the materials and workmanship to be used will produce the desired results.

Efflorescence, a white crystalline deposit that can form on concrete surfaces, can be especially visible on colored CMU surfaces. To minimize the potential for efflorescence, detail and build the wall to avoid penetration of water into the masonry, and keep the top of the wall covered when work is stopped.

Efflorescence is easiest to remove if it is cleaned promptly after it appears. A water repellent or clear glaze coating also can help reduce water penetration; test any surface-applied treatment or coating before proceeding with the application to determine the effect on masonry appearance. Caulking materials used to seal joints can be specified in colors to match the masonry.

### Operation and Maintenance Issues

Colored concrete is a permanent material that normally requires little or no maintenance. Sandblasting will remove graffiti.

### Commissioning

N/A

### Example(s)

### References/Additional Information

See References listed in Overview, above.

National Concrete Masonry Association (NCMA). 2302 Horse Pen Road, Herndon, VA 20171-3499. Tel: (703) 713-1900. Fax: (703) 713-1910. Web site: http://www.ncma.org/. The web site provides a list of certified masonry consultants.

American Concrete Institute (ACI), PO Box 9094, Farmington Hills, MI 48333-9094. Tel: (248) 848-3800. Fax: (248) 848-3801. Web site: http://www.aci-int.org/.

# Guideline IS9: Acoustical Walls and Ceilings

### Recommendation

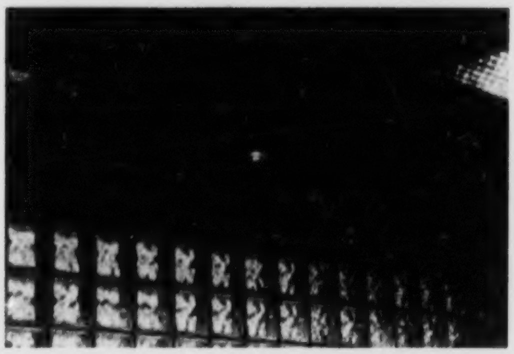
Select formaldehyde-free acoustical ceiling and wall systems with recycled-content.

### Description

Acoustical wall and ceiling systems are widely used in school for sound dampening. A variety of products are available including modular wall panels (textile and metal-covered), suspected ceiling tiles (t-bar ceilings), and surface mounted ceiling and wall panels.

Ceiling tile (usually in a T-bar ceiling) is the most common ceiling finish in schools. Because of the large ceiling surface area, the likelihood of its being disturbed during modifications/renovations, and its contact with HVAC systems, it is an important product to consider for air quality and materials efficiency.

Currently available types include recycled content ceiling tiles made of recycled newspaper, mineral wool, perlite, glass, and clay. Look for a minimum recycled content of 79%. (A recent informal survey conducted by the California Integrated Waste Management Board indicates that the recycled content of acoustical ceiling tiles varies between 18% and 82%.) Natural fiber acoustic ceiling panels are also available, for both walls and ceilings.



*Acoustical ceiling tile/T-bar ceiling installation at the Central Market, a recycled content products demonstration project, Poulsbo, Washington. Photo reprinted with permission from O'Brien & Company, Inc.*

| Applicable Spaces | | Climates | | When to Consider | |
|---|---|---|---|---|---|
| Classrooms | ■ | South Coast | ■ | Programming | ☐ |
| Library | ■ | North Coast | ■ | Schematic | ☐ |
| Mulit-Purpose / Cafeteria | ■ | Central | ■ | Design Dev | ■ |
| Gym | ■ | Mountains | ■ | Contract Docs | ■ |
| Corridors | ■ | Desert | ■ | Construction | ■ |
| Administration | ■ | | | Commissioning | ☐ |
| Toilets | ■ | | | Operation | ■ |
| Other | ■ | | | | |

### Applicability

Anywhere acoustical dampening is desired, including classrooms, gymnasiums, and large gathering areas.

### Applicable Codes

See "Applicable Codes" in Overview.

### Integrated Design Implications

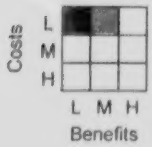
The T-bar ceiling system integrates with HVAC system ducting layout and operation. Do not use the space above the T-bar ceiling as a return air plenum because it is difficult to clean, and, if there is any off-gassing, odors, or micro-organisms from any material in this area, contaminants can spread throughout the air space and be distributed to other areas. Instead, install return air systems using dedicated metal ductwork with access hatches for inspection and cleaning. Recycle construction waste (require subcontractor to take back for recycling).

Make sure insulation is not installed directly over drop-in ceilings. Lighting fixtures, diffusers, and other equipment interrupt the insulating barrier, leading to poor insulating performance. (Often the space above the ceiling is considered an attic space, requiring outside air ventilation.)

Make sure no fiberglass is exposed in the plenum.

## Costs

Low.



## Benefits.

Recycled content acoustical products are materials efficient. At least one manufacturer (Armstrong) offers a reclamation program (see *References* below for more information).

Acoustical products from Tectum are made from wood fiber and other sustainable raw materials and are highly durable.

Ceiling tile waste, either from construction or demolition, is nontoxic (as long as lead paint was not used on older ceiling installations). One company claims that its panels can successfully be ground up and composted to produce a soil amendment.

## Design Tools

Listed in Overview, above.

## Design Details.

### General

Acoustical materials, including acoustical ceiling tiles, can act as "sinks" for the absorption of odors and VOCs from other sources (during application of paint and other finish coatings, for example) and re-emit them later. Where feasible, sequence work to avoid exposing applying VOC-containing materials in spaces with exposed acoustical surfaces. Require adequate ventilation during installation of finish materials that emit indoor pollutants.

Consult with the manufacturer before painting/coating any acoustical material. With most ceiling tiles, for example, the material loses its acoustical properties once it has been painted. Exceptions include several product lines from Tectum, which they certify for up to ten applications of a non-bridging paint.

### Walls and Panels

Low-density fiberboard is made from paper and wood fiber, available made from 100% recycled newsprint. Most processes use no glue. They are suitable for use as acoustic panels.

### Ceilings

Coordinate placement of lighting fixtures and other equipment in ceilings to provide clear access for inspection and servicing of HVAC system air filters and other components.

Where daylighting has been incorporated as a design strategy, consider using ceiling tiles with high light reflectance as specified in ASTM Standard E1477 (0.83lr).

Remove any wetted ceiling tiles from the site immediately to avoid mold contamination.

## Operation and Maintenance Issues

Ceiling tiles and other acoustical materials collect dust and absorb odors. Tile with mineral fiber content may also begin to shed hazardous fiber if disturbed, or as it deteriorates. Both problems are a particular concern where the ceiling is used for a return plenum to carry air back to the HVAC air handlers. If this type of return system is used, the tile should be checked for damage and the plenum space occasionally cleaned with a high performance vacuum. If possible, in new and renovation design, HVAC returns should be ducted instead of risking contamination by debris in suspended ceilings (See Integrated Design discussion above.)

## Commissioning

N/A

**Example(s)**

Ross Middle School, Ross, CA (Marin County)—Acoustic ceiling tile has 75% recycled content

**References/Additional Information**

See References listed in Overview, above.

Armstrong World Industries has a program for recycling old ceiling tiles, which it collects from building owners and uses as raw materials in the manufacture of new acoustical ceilings. For more information: Tel: (888) CEILINGS. Armstrong ceilings web site: http://www.ceilings.com, (From Newsbriefs, *Environmental Building News*, Oct 00, p 6). Armstrong also provides software for analyzing and comparing the acoustical performance of acoustical products.

"Natural-fiber Acoustic Ceiling Panels," Environmental Building News, Volume 7, No. 4 (April 1998). For more information about Tectum natural fiber acoustic panels and systems, go to Tectum web site: http://www.tectum.com.

Tectum web site, http://www.tectum.com. According to a Tectum rep, their biggest users are schools. For certain applications (e.g., gymnasiums), their product is lowest cost option. In its 1-inch form, it costs about $2.00 per sf to the installing contractor. It is "incredibly rugged, and you can paint it."

# Guideline IS10: Paints and Coatings

## Recommendation

Specify least toxic, formaldehyde-free, zero-VOC or low-VOC paint that meets durability and other performance requirements.

| Applicable Spaces | | Climates | | When to Consider | |
|---|---|---|---|---|---|
| Classrooms | ■ | South Coast | ■ | Programming | ☐ |
| Library | ■ | North Coast | ■ | Schematic | ☐ |
| Mulit-Purpose / Cafeteria | ■ | Central | ■ | Design Dev | ■ |
| Gym | ■ | Mountains | ■ | Contract Docs | ■ |
| Corridors | ■ | Desert | ■ | Construction | ■ |
| Administration | ■ | | | Commissioning | ☐ |
| Toilets | ■ | | | Operation | ■ |
| Other | ■ | | | | |

## Description

Emissions from paints and coatings are primarily from evaporating solvents and other volatile organic compounds (VOCs) released by oxidation. Water-based paints acrylic latex paints are lower in VOCs (<250 mg/L) than solvent-based paints. Low-VOC is generally accepted to mean paint with a VOC content less than 100 mg/L.

While a variety of low-VOC and zero-VOC paints are now available to choose from, they vary in cost, toxicity, and performance. Therefore, paint selection should consider VOC content as well as overall composition and required performance characteristics, including hideability and durability.

## Applicability

All interior painted surfaces.

## Applicable Codes

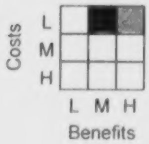
See "Applicable Codes" in Overview and OSHA and local regulations for lead-containing paint (for renovation work).

## Integrated Design Implications

Light colors enhance daylighting. Integrate with ventilation system installation/operation to provide proper ventilation during application, curing, and occupancy. Change out HVAC filters following application and before occupancy.

## Costs

Costs vary widely with paint type and application. Low-VOC, zero-VOC, and nontoxic paints have tended to cost 10 to 30% more than conventional paint, but prices are becoming more comparable as demand/production increases. Many low-VOC paints are now comparable in price to conventional paint.



| Costs | L | M | H |
|---|---|---|---|
| L | ☐ | ■ | ▨ |
| M | ☐ | ☐ | ☐ |
| H | ☐ | ☐ | ☐ |

Benefits

## Benefits

"Zero-VOC" or low-VOC paints minimize the indoor air pollution load and health risks to both workers and occupants. Water-based paints are generally safer to handle and can be cleaned up with water, reducing health risks to workers and minimizing/avoiding hazardous waste. Leftover latex paint may be recyclable, thus reducing waste.

## Design Tools

Listed in Overview, above.

## Design Details

Where practicable, leave surfaces of exposed structure unpainted.

A paint can be "low-VOC" yet still contain odorous, toxic, or otherwise undesirable ingredients such as ammonia, formaldehyde, crystalline silica (a known carcinogen in dust form[7]), acetone, odor masking agents, and many other compounds, including fungicides and bactericides. Some of these may not be an *air quality* problem for occupants, but they may be hazardous to painters and those involved in manufacture of the paint. In addition, hazardous ingredients can degrade the natural environment during production and after disposal. Look for water-based paints that are formaldehyde-free, Zero- or low-VOC, *and* low-toxic.

Specify products containing no lead, mercury, hexavalent chromium or cadmium. Though regulations have nearly eliminated many toxic components from consumer paint lines, industrial and commercial paints may still contain them. Check the MSDS's; all toxic contents must be disclosed.

High traffic areas or areas vulnerable to graffiti may call for a more durable and smoother (enamel) finish. These paints typically have a higher VOC content. (While there is little official test data comparing "high-durability" and low-VOC paints, anecdotal information suggests that "high-durability" (usually alkyd paint) products would be expected to show roughly twice the performance of low VOC paints.) Due to their higher VOC content, the high durability paints will require a longer time for out-gassing, and as a result could contribute to indoor air quality problems. One manufacturer stated that, while this time will vary widely with environmental conditions (temperature and humidity) and film thickness, an estimate is six weeks for a person with high sensitivity.

If possible, the selection process should include a side-by side paint comparison of the various products being considered, and should include comparison of abrasion resistance (durability), hideability, volume solids, odor, and overall appearance and feel. Final paint selection should consider the following elements:

1. What is the allowable drying cycle for initial painting and subsequent maintenance cycles? Will time between paint application and building occupancy be as long as six weeks (a goal for the higher VOC paints), or be shorter? Is the paint locally available? (An important consideration for future maintenance.)
2. What is the durability required? Requirements will likely vary with the space. For example, one manufacturer had specific and different recommendations for gymnasiums, cafeterias, restrooms, general classrooms, and hallways.
3. What is the method of application? Choices such as in-house versus contractor and spray versus roller, have a bearing on paint choice.
4. What are the budget constraints, including first-time and maintenance? Budget analysis should consider not just cost per gallon, but also evaluate area coverage per gallon, which can vary.

### Installation

Specify isolation requirements (isolation of construction zones from completed zones to prevent cross-contamination; removal, coverage, or isolation of porous materials to avoid their absorption and subsequent re-emission of solvents, maintaining negative ventilation in construction areas). When sanding dried paint, a dust mask should be worn.

---

[7] Some low-VOC paints contain crystalline silica, a known carcinogen. One manufacturer's representative stressed that this ingredient is not a hazard in the wet paint—it is an issue only when dried paint is sanded, and dust is generated.

## Operation and Maintenance Issues

Review recommended duration between paint application and occupancy and review for compatibility with maintenance schedules/requirements. Ideally, work should be scheduled during unoccupied periods or periods of least occupancy. Large projects should be scheduled during the summer vacation months or other breaks. The maintenance schedule should also factor in manufacturer recommended air temperatures for application.

> ***Caution***
>
> *In jobs that require removal of old paint and may require chemical strippers, closely observe manufacturers recommendations for use, including ventilation and personal protective equipment.*
>
> *If performing renovation at a school constructed prior to 1980, do not begin work until testing paint samples for possible lead contamination. If lead-containing paint is present, observe appropriate abatement controls.*

Where possible, perform painting and stripping off-site or select materials with factory-applied finishes. For on-site interior painting, cover surfaces, such as fabric-covered furnishings, that may absorb VOCs. Consider constructing barriers (for example, walls or curtains of plastic sheeting) to help isolate portions of larger areas and minimize the distribution of dust and other pollutants.

Wipe down all surfaces with a wet cloth as soon as practical after completing all dust-generating work typically associated with surface preparation.

Carefully observe manufacturers recommendation for cleanup, storage, and disposal, for paints, primers, and thinners. (Note: Some products are classified as "flammable liquids" under federal regulations and must e stored in a specifically constructed safety cabinet.) Keep paint containers covered as much as possible during and following use to protect against VOC release. For excess paint, consider recycle/reuse options.

All paint containers with residual liquid must be disposed of as hazardous waste per EPA regulations. Only dry containers can be placed in municipal landfills.

## Commissioning

N/A

## Example(s)

Ross Middle School, Ross, CA (Marin County)—Interior wall & ceiling paint is "zero" VOC formulation

Bainbridge Island High School (Bainbridge Island, Washington)—As part of a major renovation at the existing high school, Capital Works personnel, with assistance from an environmental consultant, conducted an investigation of locally available, low-VOC paint options. The investigation comprised a review of product data, including MSDS's, and a side-by-side paint comparison of several products for attributes including abrasion resistance, hideability, volume solids, odor, and overall appearance.

## References/Additional Information

References listed in Overview, above, and:

*Interior Painting and Indoor Air Quality in Schools.* Published by the School Facility Branch of the Maryland State Department of Education. To order, contact the Maryland State Department of Education, Division of Business Services, School Facilities Branch, 200 W. Baltimore St., Baltimore, MD 21201. Phone for Capital Projects Assistant Manager: (410) 767-0097.

# Guideline IS11: Casework and Trim

## Recommendation

Specify casework and trim constructed from formaldehyde-free, environmentally preferable materials. Design for easy of future disassembly and reuse. Install with least toxic, low-VOC adhesives and coatings.

Formaldehyde

| Applicable Spaces | | Climates | | When to Consider | |
|---|---|---|---|---|---|
| Classrooms | ■ | South Coast | ■ | Programming | □ |
| Library | ■ | North Coast | ■ | Schematic | □ |
| Mulit-Purpose / Cafeteria | ■ | Central | ■ | Design Dev | ■ |
| Gym | ■ | Mountains | ■ | Contract Docs | ■ |
| Corridors | ■ | Desert | ■ | Construction | ■ |
| Administration | ■ | | | Commissioning | □ |
| Toilets | ■ | | | Operation | □ |
| Other | ■ | | | | |

## Description

Conventional particleboard is made with bonding agents that use urea-formaldehyde, which can off-gas VOCs for years after application. (Please see discussion of formaldehyde-related indoor air quality problems in the Overview.) Some practitioners recommend coating the particle board with a sealer to prevent off-gassing of formaldehyde and other volatiles (see Caution callout, below). However, CHPS recommends using only products that are formaldehyde-free for interior use in high performance schools.

Environmentally preferable product alternatives for interior casework and/or trim include exterior grade plywood with phenolic formaldehyde resin, formaldehyde-free medium density fiberboard (MDF), oriented strand board (OSB), certified wood, salvaged lumber, bamboo, recycled plastic, metal, biocomposites (only for areas not subject to frequent wetting), and engineered wood. Pre-assembled cabinets made with nontoxic materials and finishes, solid wood, engineered wood, and enameled metal are also available.

## Applicability

All interior casework and trim.

## Applicable Codes

See "Applicable Codes" in Overview.

## Integrated Design Implications

N/A

## Costs

There is a cost premium for certified wood, ranging from modest to significant, depending upon quantity, type, and current availability. Engineered wood often costs less than virgin lumber.

Costs

| | L | M | H |
|---|---|---|---|
| L | ■ | | |
| M | | ▨ | |
| H | | | |

Benefits

## Benefits

Formaldehyde-free products and low toxic glues/adhesives and coatings minimize the indoor air pollution load and health risks to both installers and occupants. Certified wood is produced in a way that is ecosystem-protective. Products made from certified hardwoods are durable and reusable.

Engineered lumber makes use of wood waste that would otherwise be discarded. Products made with engineered wood have low moisture content and so are warp- resistant and shrink-resistant, adding to their durability. The products are strong, and their predictable qualities lead to less rework.

Bio-composites materials are made from natural, renewable resources including straw, recycled paper products, and a soy-based resin systems.

## Design Tools

Design Tools listed in Overview, above, and:

*Certified Forest Products Database,* Certified Forest Products Council, http://www.certifiedwood.org. 14780 SW Osprey Dr., Suite 285, Beaverton, OR 97007. (503) 590-6600. Industry information on suppliers and standards.

## Design Details

Design interior building components for future disassembly, reuse, and recycling.

### Selection

Environmentally preferable alternatives include:

If using certified hardboards, choose woods grown in regional forests, which reduces the energy consumption involved in transportation. Woods common to the western area include pine, aspen, spruce, fir, and hemlock.

For casework, consider urea formaldehyde-free medium density fiberboard (MDF), or equal, exterior grade plywood (made with phenolic formaldehyde, which is less harmful than the urea formaldehyde in interior grade products).

***Caution***

*Many of the engineered lumber products contain formaldehyde or other chemicals that are detrimental to the environment and to indoor air quality. Some types of particleboard are now being manufactured with resin binders that do not contain formaldehyde. If non-formaldehyde containing particleboard or plywood products are not available, select exterior grade plywood in lieu of interior grade products. Exterior grade contains phenol formaldehyde, which is less harmful than the urea formaldehyde in interior grade plywood.*

*Note: Some practitioners recommend coating conventional particleboard with an impermeable sealant to prevent outgassing of formaldehyde and other volatiles. However, others disagree that this is effective mitigation.*

Consider veneered wood panels, such as oriented strand board (OSB) with hardwood facing, for cabinets and millwork. If installed for easy removal, they are reusable.

Bamboo can be used for countertops. Also consider biocomposites for countertops in reception or other high profile (but not wet) areas.

Low-density fiberboard is made from paper and wood fiber, available made from 100% recycled newsprint. Most processes use no glue. They are suitable for uses such as underlayment and tackboards.

Recycled plastic panels made from consumer product waste are available for functional work tops. If installed for easy removal, they are reusable.

Vegetable oil based plastics are available in both flexible and rigid types. They can be colored and filled with minerals, metal shavings, or other plastic waste and wood fiber giving them a large range of texture and color possibilities. If installed for easy removal, these also have good reuse potential.

Fiber reinforced cement boards made with recycled fiber are a durable, materials efficient choice for use as substrates for tile and decorative finishes. If installed for easy removal, these also have good reuse potential.

### Installation

Dust from cutting and the emissions from glues used for installation are indoor air quality issues during and after installation. Specify work to be performed in a shop off the premises where practicable. Require installer to use the smallest amount of adhesive/sealant necessary to fulfill the manufacturer's performance specifications for that product. Specify use of adequate ventilation and VOC—safe worker masks. Where appropriate, specify installation to permit easy removal and reuse, for example, screwed assembly instead of glued.

Note: Woods naturally emit formaldehyde, but in minute amounts.

### Operation and Maintenance Issues

Will vary with type of material selected, but are similar to requirements for traditional materials.

### Commissioning

N/A

### Example(s)

Ross Middle School, Ross, CA (Marin County)—Cabinets are made with low formaldehyde MDF board. Used low VOC adhesives, sealants, and clear sealers.

### References/Additional Information

References listed in Overview, above.

For general information on certified lumber, contact: Certified Forest Stewardship Council, Jeff Wartelle. Tel: (503) 590-6600. Industry group provides information on distribution and other assistance.

*Certified Forest Products Database,* Certified Forest Products Council. Web site: http://www.certifiedwood.org. Contact: 14780 SW Osprey Dr., Suite 285, Beaverton, OR 97007. Tel: (503) 590-6600. Industry information on suppliers and standards.

Two private companies in the U.S. are authorized to issue the FSC stamp of approval: Scientific Certification Systems (SCS) in Oakland, CA (http://www.scs1.com/forestry1.shtml), and SmartWood Certified Forestry, based in Richmond, VT, with an affiliate in Oregon (http://www.isf-sw.org/cert.htm).

The American Bamboo Society. Web site: http://www.bamboo.org/abs.

APA -The Engineered Wood Association. Tel: (206) 565-6600. Web site: http://www.apawood.org. Email: product.support@apawood.org

American Institute of Timber Construction. Tel: (303) 792-9559. Fax: (303) 792-0669. Web site: http://www.aitc-glulam.org. Email: webmaster@aitc-glulam.org.

American Wood Council. Tel: (202) 463-2700. Web site: http://www.awc.org/. Email: AWCINFO@afandpa.ccmail.compuserve.com.

National Particleboard Association. Tel: (301) 670-0604. Web site: http://www.pbmdf.com. Email: info@pbmdf.com.

Western Wood Products Association. Tel: (503) 224-3930. Web site: http://www.wwpa.org. Email: info@wwpa.org.

Phenix Biocomposites, LLC. Makes a variety of engineered panel products using agricultural byproducts and other renewable, sustainable and recycled resources. Tel: (800) 324-8187. Web site: http://www.phenixbiocomposites.com.

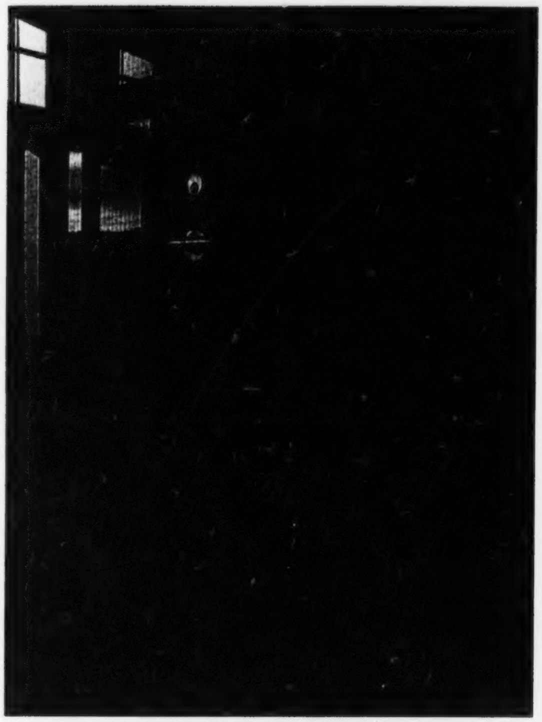
# Guideline IS12: Interior Doors

## Recommendation

Select formaldehyde-free interior doors constructed with recycled content or from certified wood. Avoid particle core board doors, which contain urea-formaldehyde and luan doors, which are made from wood harvested from rain forests. Select pre-finished products, if possible. If finishing on-site, select low toxic, low-VOC coatings.

## Description

Interior doors are usually wood, molded hardboard, or hollow core. Luan plywood is harvested from rain forests, so it should be avoided unless it has a FSC or other certification. Molded hardboard is often made with recycled material and pressed into shape, but some is made with urea-formaldehyde and should be avoided. If using solid wood doors, select products with FSC or other certification (clear stock is becoming rare and if uncertified, often comes from old-growth forests.)



*Randy Karels, photographer.*

| Applicable Spaces | | Climates | | When to Consider | |
|---|---|---|---|---|---|
| Classrooms | ☐ | South Coast | ■ | Programming | ☐ |
| Library | ☐ | North Coast | ■ | Schematic | ☐ |
| Mulit-Purpose / Cafeteria | ☐ | Central | ■ | Design Dev | ■ |
| Gym | ☐ | Mountains | ■ | Contract Docs | ■ |
| Corridors | ☐ | Desert | ■ | Construction | ■ |
| Administration | ☐ | | | Commissioning | ☐ |
| Toilets | ☐ | | | Operation | ■ |
| Other | ☐ | | | | |

## Applicability

All spaces.

## Applicable Codes

See "Applicable Codes" in Overview

## Integrated Design Implications

N/A

## Costs

Low.

## Benefits

Avoiding luan and solid wood doors helps protect limited forest resources. Formaldehyde free protects indoor air quality and heath. Low-toxic finish coatings minimize indoor air pollution load and health risks to both installers and occupants.

| Costs | L | M | H |
|---|---|---|---|
| L | ■ | ▨ | ☐ |
| M | ☐ | ☐ | ☐ |
| H | ☐ | ☐ | ☐ |

Benefits

## Design Tools

See Overview, above.

## Design Details

N/A

## Operation and Maintenance Issues

May require periodic re-coating for aesthetic purposes. Type of paint determines the ability to clean the surface.

## Commissioning

N/A

## Example(s

## References/Additional Information

See Overview, above.

# Guideline IS13: Toilet Partitions

## Recommendation

Select high durability, solid plastic toilet and shower partitions with recycled content.

## Description

There are available styles of toilet partitions, including baked enamel over metal, plastic laminate over particleboard and solid plastic panel. Solid plastic toilet/shower partitions are the most durable type overall. Recycled content products are made with a post-consumer HDPE content between 20% and 35%, depending on the manufacturer. In addition, some makes contain postindustrial plastic material.

*High-density polyethylene (HDPE) restroom partitions are maintenance-friendly and durable. Photo reprinted with permission from Santana Solid Plastic Products.* *http://www.santanaproducts.com*

| Applicable Spaces | | Climates | | When to Consider | |
|---|---|---|---|---|---|
| Classrooms | ☐ | South Coast | ■ | Programming | ☐ |
| Library | ☐ | North Coast | ■ | Schematic | ☐ |
| Mulit-Purpose / Cafeteria | ☐ | Central | ■ | Design Dev | ■ |
| Gym | ☐ | Mountains | ■ | Contract Docs | ■ |
| Corridors | ☐ | Desert | ■ | Construction | ■ |
| Administration | ☐ | | | Commissioning | ☐ |
| Toilets | ■ | | | Operation | ■ |
| Other | ■ | | | | |

## Applicability

All toilet/shower partitions.

## Applicable Codes

See "Applicable Codes" in Overview.

## Integrated Design Implications

N/A

## Costs

Recycled content units cost 20% more than conventional units, but are more durable, require less maintenance, and reusable.

| Costs | L | M | H |
|---|---|---|---|
| L | ■ | ☐ | ☐ |
| M | ☐ | ▨ | ☐ |
| H | ☐ | ☐ | ☐ |

Benefits

## Benefits

Recycled content partitions are materials-efficient, low maintenance, and graffiti/vandal resistant.

## Design Tools

Listed in Overview, above.

See also Santana Solid Plastics Products, http://www.santanaproducts.com/html/toiletpartitions.html, for sample specifications for solid plastic, recycled content toilet partitions, floor-mounted, ceiling mounted, and floor-to-ceiling models.

## Design Details

N/A

## Operation and Maintenance Issues

N/A

### Commissioning

N/A

### Example(s)

Cold Spring Elementary School—used recycled content toilet partitions.

### References/Additional Information

Listed in Overview, above

*Designing with Vision: A Technical Manual for Material Choices in Sustainable Construction.* Revised July 2000. A publication of the California Integrated Waste Management Board. See Chapter 8, "Strategies to Reuse Materials and Reduce Material Use in Construction," Appendix E sample specifications for: Section 10160; Solid Plastic Partitions. *Designing with Vision* can be downloaded in four parts from http://www.ciwmb.ca.gov/GreenBuilding/. Chapter 8 is in Part D.

# ELECTRIC LIGHTING AND CONTROLS

Electric lighting is one of the major energy uses in schools. Enormous energy savings are possible through the use of efficient equipment, effective controls and careful design. Using less electric lighting reduces a major source of heat gain, thus saving air-conditioning energy, increasing the potential for natural ventilation, and reducing the space's radiant temperature (improving thermal comfort). Electric lighting design also strongly affects visual performance and visual comfort, by maintaining adequate, appropriate illumination, and by controlling reflectance and glare. Finally, visual and accessible light and power meters can educate students and faculty about how lighting systems and energy controls work.

This chapter provides guidelines for:

- Pendant-mounted lighting (Guideline EL1)
- Recessed lighting (Guideline EL2)
- Surface-mounted lighting (Guideline EL3)
- Lighting controls for classrooms (Guideline EL4)
- Gym lighting (Guideline EL5)
- Corridor lighting (Guideline EL6)
- Lighting for a multipurpose room (Guideline EL7)
- Lighting for a library or media center (Guideline EL8)
- Lighting for offices and teacher support rooms (Guideline EL9)
- Lighting for locker and toilet rooms (Guideline EL10)
- Outdoor lighting (Guideline EL11)

## Overview

This section outlines lighting quality issues, lighting technology, lighting energy use, and important lighting issues such as design criteria, maintenance, and lighting control commissioning. These factors all affect the design, installation, and maintenance of lighting systems in different school building spaces such as those described in the accompanying guidelines.

## Visual Tasks in Schools

### Common Visual Tasks

School visual tasks vary in terms of size, contrast, viewing angle and distance. Many of these tasks require close attention for prolonged periods of time. Critical visual tasks common to all school environments include:

- Writing
- Reading printed material
- Reading material on visual display terminals (VDTs)
- Reading from blackboards, whiteboards, overhead and video projections, and bulletin boards

### Additional School Tasks

In addition to the reading and writing visual tasks common to all school environments, there are a number of more specialized activities that may occur in specific circumstances. Some of these activities require specialized lighting equipment and design. Examples include:

- Drawing, painting and other art work
- Laboratory work
- Food preparation
- Performance activities, such as dramatic productions and debates
- Sports
- Home economics activities, including sewing and cooking
- Industrial education activities, such as metal shop and wood shop

One notable difference between schools and other environments is that students must constantly adapt their vision between "heads up" and "heads down" reading conditions. Copying a homework assignment from the blackboard into a notebook, for instance, requires the eyes to adjust for differences in visual target size, distance, contrast and viewing angle. To create comfortable, productive spaces the lighting design must address the quality of the entire visual environment, instead of merely accounting for horizontal illuminance, as is too often the case.

## Lighting Quality Issues

Lighting in schools should provide a visual environment that enhances the learning process for both students and teachers. This can occur only if people can perform their visual tasks quickly and comfortably. This section outlines several lighting quality issues that are important in school lighting. Table 8 provides information about the relative important of various lighting quality issues for specific spaces in schools.

*Table 8 – Lighting Quality Issues for Sample School Building Spaces*

| | General Classroom | Computer Classroom | Multipurpose Classroom | Corridor |
|---|---|---|---|---|
| Control of direct and reflected glare | ⦿ | ● | ⦿ | ○ |
| Light on walls and ceiling | ● | ● | ● | ⦿ |
| Fixture location related to people | ⦿ | ● | ⦿ | ○ |
| Light patterns – uniformity vs. shadows | ⦿ | ● | ⦿ | ○ |
| Daylight | ⦿ | ○ | ⦿ | ⦿ |
| Color rendering and color temperature | ⦿ | ⦿ | ⦿ | ⦿ |
| Lighting controls, flexibility | ● | ⦿ | ● | ○ |
| Quantity of light – horizontal | 30 fc | 30 fc | 50 fc | 5 fc |
| Quantity of light – vertical | 30 fc | 30 fc | 30 fc | 10 fc |

● Very Important ⦿ Important ○ Somewhat Important

**Quantity of Light**

Too often, schools are designed with excessively high horizontal light levels. While modern classrooms only need about 30-50 footcandles of illumination (see Table 8), past recommendations have called for as much as 100 footcandles of illumination for reading tasks. In large part, these recommendations reflected the difficulty of performing tasks such as reading second or third generation carbon copies, mimeograph copies or faded newsprint. However, technological advances in office equipment and computers have greatly improved the visibility of most reading tasks. Laser copier print, for example, is much easier to read than mimeograph copy. And for drafting and other computer work, the visual task is self-illuminated. Many published school lighting design parameters remain based on antiquated standards calling for excessively high horizontal illuminance. Too often, this results in poor lighting quality, reduced visual performance, wasted lighting energy, and high energy and maintenance costs.

As part of an overall de-emphasis on horizontal illuminance, lighting quantity requirements have changed significantly in recent years. Part of this is due to an increasing concern with the entire visual environment. Better lighting designs don't stop with horizontal illuminance levels, but also focus on lighting quality issues such as uniformity, vertical illuminance, and glare avoidance.

In 1999, the Illuminating Engineering Society of North America (IESNA) revised its recommended lighting design procedure, and issued new recommendations for horizontal illuminance. ***The recommended horizontal illuminance level for most typical classroom and office reading tasks is now 30 footcandles***, as shown in Table 9. Some classroom tasks may justify up to 50 footcandles, so choosing between 30 and 50 is an excellent compromise.

*Table 9 – IESNA Recommended Illuminance Levels*

| *Category* | *Description* | *Recommended Illuminance (fc)* |
|---|---|---|
| Orientation and Simple Visits | Public Spaces | 3 fc |
| | Simple orientation for short visits | 5 fc |
| | Working spaces where simple visual tasks are performed | 10 fc |
| Common Visual Tasks | **Performance of visual tasks of high contrast and large size** | **30 fc** |
| | **Performance of visual tasks of high contrast and small size, or visual tasks of low contrast and large size** | **50 fc** |
| | Performance of visual tasks of low contrast and small size | 100 fc |
| | Performance of visual tasks near threshold | 300 – 1,000 fc |

Source: *IESNA Lighting Handbook, 9th ed., p. 10-13*

IESNA's new lighting design procedure comprises a six-step process that emphasizes the relative importance of numerous design issues for specific applications. These design issues include color appearance, daylighting integration and control, luminances of room surfaces, reflected glare, and many other issues. For more information about IESNA's new lighting design procedure, refer to the on-line Appendix of the Best Practices Manual, located at http://www.chps.net/.

### Vertical Illumination

Achieving adequate vertical illumination is one of the more critical design issues in school lighting. With the exception of desktop reading, nearly all school visual tasks are "heads up" type activities requiring proper vertical illuminance. In addition, much of the perception of what comprises lighting quality is strongly influenced by vertical illumination. For example, proper wall illumination is a critical factor in obtaining lighting uniformity in classrooms. Similarly, in nighttime environments, vertical illumination that promotes facial recognition is important in creating a sense of safety and security. In addition, good vertical illumination is important for promoting the important school activity of social communication.

### Glare Control

Light sources that are too bright create uncomfortable glare. In extreme cases, direct or reflected glare can also impair visual performance by reducing task visibility. Since the eye has to work much harder to perform in such a case, fatigue results. All sources of light, including daylight, must be carefully controlled to avoid causing discomfort or disabling glare. Common glare problems in classrooms include uncomfortable overhead glare from direct distribution luminaires, reflected luminaire imaging on visual display terminals and whiteboards, and direct glare from uncontrolled windows or skylights.

### Lighting Uniformity

For the most part, illuminate school-building spaces as uniformly as possible, avoiding shadows or sharp patterns of light and dark. For classrooms, luminance contrast ratios between the visual task and its immediate surround should not exceed 3:1, and contrast between the brightest surfaces in the visual field and the visual task should not exceed 5:1. Higher ratios contribute to fatigue, because the eye is constantly adapting to differing light levels. Use of recessed or surface-mounted parabolic fixtures should be avoided in most spaces, as they block light from reaching the upper portion of the wall, creating a shadowy, cave-like environment. Very bright sources, such as T-5 straight, twin tube and T-5HO straight lamps, should only be used in high spaces like gyms, or in cove lighting or in indirect luminaires in ordinary classrooms and other spaces

Maximize overall lighting uniformity by following guidelines for maximum spacing of luminaires. The best method of maximizing uniformity is to make a concerted effort to light vertical surfaces, as well as to light the ceiling (using indirect or indirect/direct luminaires) whenever possible. Using-light colored diffuse surface materials also serves to optimize lighting uniformity.

### Color Rendering

Light sources that render color well enhance the visual environment. Light sources should have a minimum color-rendering index (CRI) of 75 for most interior spaces. For areas such as art classrooms where accurate color rendition is more critical, consider using a source with a higher CRI of at least 80. The latest "second generation" T-8 lamps, T-5 lamps and most compact fluorescent lamps have CRI in the range of 82-86.

### Lighting Control Flexibility

Lighting controls should be designed for flexibility to accommodate the varying nature of many school spaces. In addition to saving energy, bi-level or multiple level switching enables selection of different light levels to respond to changing requirements. Separate circuiting of luminaires in daylit zones also enhances space flexibility and energy savings. Control flexibility also improves lighting energy performance by encouraging only the use of lights that are needed for the activity at hand.

Control flexibility is especially important in classrooms, which typically must be responsive to varying illumination schemes due to a wide variety of conditions and activities that occur. It is especially critical that teachers have the ability to override any automatic dimming and/or occupancy sensor controls, so that they can switch the lights off manually when needs warrant.

In multipurpose spaces, it may be necessary to design several different lighting control schemes to account for all the different activities. In these cases, it may make sense to specify a preset dimming or switching system allowing one-button scene changing.

Lighting control systems must also be easy to understand and operate. Non-intuitive control interfaces are likely to be ignored at best, and disabled in more extreme cases.

### Integration with Daylight

Properly controlled daylight is conducive to comfort and productivity. Integrating electric light with daylight is one of the more challenging aspects of school lighting design. At a minimum, luminaires should be circuited to match the dispersion of daylight into the space.

Thus, luminaires closest to windows or skylights should be circuited separately from the remainder of the lighting in the space. This promotes the energy-saving nature of daylight by allowing luminaires in daylit zones to remain off during most daylight hours. For a lighting system that maximizes energy savings and flexibility, consider using dimming ballasts with manual or automatic dimmers for additional flexibility. Daylighting design is described in detail in the next chapter.

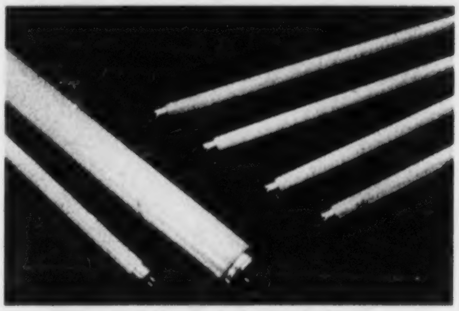
## Light Sources

A wide variety of light sources are available to light schools. Light source selection critically affects building space appearance, visual performance and comfort. This section outlines the different types of sources available to the designer. For more detailed information about these technologies, refer to the on-line Appendix that supports the Best Practices Manual (see www.CHPS.net).

### Incandescent and Halogen Lamps

Incandescent lamps represent the oldest of electric lighting technologies. Advantages of incandescent technology include point source control, high color performance, instant starting, and easy and inexpensive dimming. Disadvantages include low efficacy, short lamp life and high maintenance costs.

Incandescent sources should not be used in new schools except in very limited and special accent lighting circumstances. Examples might include dimming applications where color performance, beam control, and/or dramatic effect is critical, such as teleconferencing rooms, theaters, and the highlighting of artwork. In most of these cases halogen sources, which offer longer life, better point source control, and crisper color performance, are superior to standard incandescent lamps.



*Conventional T-12 lamps shown next to new small diameter T-5 lamps*

### Fluorescent Lamps

Fluorescent lamps can and should be used to light nearly all types of school building spaces. They offer long life, high efficacy, good color performance, and low operating and maintenance costs. There are no inherent disadvantages to fluorescent technology; however, dimming fluorescent lamps requires special electronic ballasts that cost more than standard high frequency ballasts.

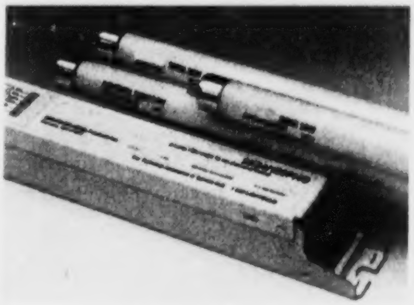
Several different types of fluorescent lamps are worth noting. These are described in Table 10.

*Table 10 – Summary of Fluorescent Lamp Technology*

| Type of lamp | Advantages/Disadvantages | Applications |
|---|---|---|
| T-12 | Relatively antiquated technology. Supplanted by newer technologies. | Some low temperature applications, such as cafeteria food storage areas. |
| T-8 | Advantages include higher efficacy, more design options, better color rendition, reduced flicker and less noise than T-12s. Newly available "premium" T-8 lamps offer higher color rendition, higher maintained lumens, and a 20% increase in lamp life over standard T-8s. | Most general lighting applications in schools, including classrooms, offices, multipurpose rooms and libraries. |
| T-5 | Similar performance to T-8 lamps, but more compact lamp envelope (5/8 in. vs. 1 in. diameter). T-5 luminaires should be well shielded to minimize glare. | Smaller profile luminaires. Especially effective in indirect luminaires, cove lighting systems, and wall washers. |
| T-5 High Output (T-5HO) | An exciting development in fluorescent lamp technology.<br>One T-5HO lamp produces nearly the equivalent maintained lumens as two standard T-8 lamps.<br>May allow designer to increase the spacing between direct/indirect luminaire rows, as compared to a typical T-8 design, which promotes use of fewer lamps and/or fewer luminaires, reducing lighting maintenance costs.<br>Currently more expensive than T-8 designs. | Due to their intense surface luminance, they must be used in well-shielded luminaires to avoid glare.<br>Can be used in some high-bay applications that previously required high intensity discharge (HID) sources. |

### Fluorescent Ballasts

Electronic high frequency ballasts are now standard equipment for most fluorescent sources. In addition to their efficiency advantages, electronic ballasts reduce flicker and ambient noise, and are available in a variety of ballast factor configurations, allowing the designer to "tune" light levels based on the ballast specification.



*Electronic Ballast*

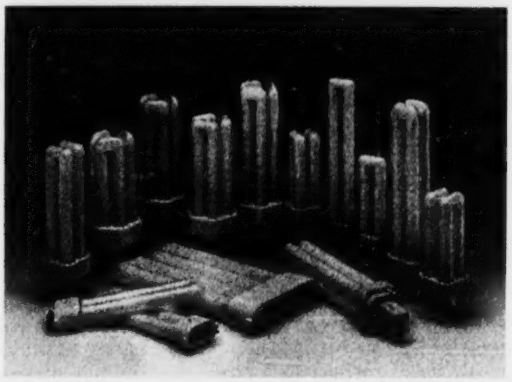
Consider the following recommendations for fluorescent ballasts. Refer to the on-line Appendix for more information about fluorescent ballast technology.

- Consider using reduced light output (RLO) electronic ballasts in building spaces lighted with fluorescent lamps where lower light levels will suffice. RLO ballasts reduce light output to approximately 75% of rated light output. Applicable spaces might include corridors, rest rooms, storage areas and similar spaces. The reduction in light output corresponds to lower input wattage, thus reducing lighting demand and energy use.
- Electronic ballasts for fluorescent lamps employ one of two methods to start the lamps, rapid-start and instant start ballasts.
- For maximum energy performance, use instant-start ballasts in areas where the lights are unlikely to be subject to a lot of on-off cycling. In areas with more frequent switching, specify rapid-start ballasts to maximize lamp life. Newer products, known as "programmed rapid-start" ballasts, are optimized for use with occupancy sensors and in spaces where switching is more frequent.
- Dimming ballasts for fluorescent lamps require an additional investment, but increase lighting system performance by optimizing space appearance, occupant satisfaction, system flexibility and energy efficiency. Dimming fluorescent ballasts should be considered in all cases requiring maximum energy performance and light level

flexibility. They are particularly effective in daylit classrooms, computer classrooms, audio video rooms and similar spaces.

**Compact Fluorescent Lamps**

Compact fluorescent lamps (CFLs) can be used in nearly all applications that traditionally have employed incandescent sources. CFLs offer excellent color rendition, rapid starting and dimmability. A large palette of different lamp configurations enhances design flexibility. Principal advantages of CFLs over incandescent sources include higher efficacy and longer lamp life. They can be dimmed, though dimming CFL ballasts are expensive. In colder outdoor environments, they can be slow to start and to come to full light output.



*Compact Fluorescent Lamps. Courtesy Sylvania*

Use CFL lamps extensively in task and accent lighting applications, including wall washing, supplementary lighting for visual tasks requiring additional task illumination above ambient levels, and portable task lighting in computer environments. They are also valuable for medium to low-level general illumination in spaces such as lobbies, corridors, restrooms, storage rooms and closets. In most non-mountain California climates they are quite suitable for outdoor corridors, step lighting, and lighting over doorways. High wattage BIAX-type CFLs can be used for general space illumination in recessed lay-in troffers (see Luminaires section below), as well as in more decorative direct/indirect luminaires for office lobbies, libraries and other spaces requiring a more "high end" look.

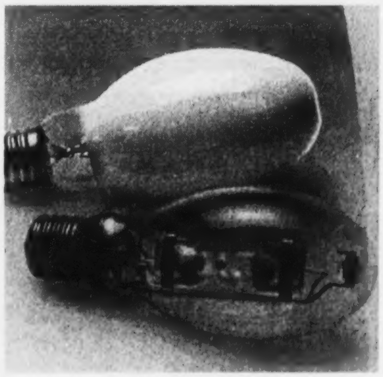
Electronic high frequency ballasts are now standard equipment for most fluorescent sources. Ballast manufacturers are gradually phasing out the production of many older technology electromagnetic ballasts, most of which will be legislated out of existence in 2002. In addition to their efficiency advantages, electronic ballasts reduce flicker and ambient noise, and are available in a variety of ballast factor configurations, allowing the designer to "tune" light levels based on the ballast specification. Normal light output (NLO) ballasts operate lamps at about 88% of rated light output. Reduced light output ballasts (RLO) ballasts reduce light output to approximately 75% of rated light output. High light output (HLO) ballasts are also available to increase light output to as much as 120% of rated levels. In addition there is a nearly linear relationship between ballast factor and system input wattage (see Table 11).

*Table 11 – Fluorescent Lamp/Ballast Power*

| Lamps per ballast | Type of Ballast | Input power per ballast |
|---|---|---|
| (2) F32T8 | Normal (BF=0.87) | 58–60 |
| (4) F32T8 | Normal (BF =0.87) | 110–112 |
| (2) F32T8 | Low light (BF=0.78) | 50–51 |
| (4) F32T8 | Low light (BF=0.76) | 99–100 |
| (2) F32T8 | High light (BF=1.20) | 78–84 |

### High Intensity Discharge (HID) Lamps

HID lamps provide the highest light levels of any commercially available light source in a wide variety of lamp wattages and configurations. In addition, they offer medium to high efficacy and relatively long lamp life. The principal disadvantage to HID sources is that they start slowly and take time to warm up before coming to full brilliance. This makes them difficult to use in many automatic lighting control scenarios without the use of expensive two-level switching systems. In some applications, such as warehouses and vehicle maintenance areas, this may be cost effective when evaluated from a life-cycle cost perspective, but be prepared for reduced color performance and lamp life if used with metal halide lamps. Dimming HID lamps is expensive and unreliable, and not recommended



*High Intensity Discharge Lamps*

For more about HID lamps and ballasts, see the on-line Appendix that supports the Best Practices Manual.

### Light Emitting Diodes (LEDs)

LEDs are semiconductor devices that generate an intensely directional, monochromatic light. Research today is directed at producing a commercially viable white LED source. At this time, because selection is mainly limited to red, blue or green products, LED use as a light source in schools is generally limited to exit signs and other signs. The principal advantage of LEDs over other sources is their extremely long life. In addition, a two-sided LED exit sign can usually be illuminated with less than 5 watts.

LEDs are highly recommended for use in school exit signs. They offer high efficacy and very low maintenance costs when compared with either incandescent or fluorescent products, and are available in most of the popular exit sign configurations.

### Energy Efficient Choices

Lamps convert electricity (watts) to light energy (lumens); and most modern lamps require a ballast to regulate the power flow into the lamp. The efficacy of the conversion is measured in lumens of light output divided by watts of electric power input. The input watts include both the lamp and the ballast. **In general, it is best to use the system with the highest possible efficacy that is suited for the project.**

Some electric lamps emit less light as they age, called *lumen depreciation*. Significant improvements in certain lamps make this a very important consideration. Lamps are now rated in *mean lumens per watt (MLPW)*, which better represents the efficacy of the lamp over its life.

Table 12 gives the MLPW for a variety of lamp/ballast systems and may be used to select light sources. Be careful to follow it closely to get the best efficacy. For instance, "premium" T-8 lamps are the best overall choice for most applications, and you can use 835 (neutral color), 830 (warm color) or 841 lamps (cool color) and get the same efficacy. But if you substitute 735 color (which is cheaper), the MLPW drops to less than 80.

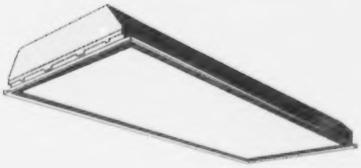
*Table 12 – Lamp Application Guidelines*

| MLPW* | Lamp Type | CRI | Ballast | Good applications | Limitations |
|---|---|---|---|---|---|
| 92 | T-5 standard 4' lamps (F28T5/835) | 86 | Electronic | Specialty lighting such as valences, undercabinet, coves, and wallwash | Not for troffers; produce a limited amount of light |
| 90 | T-8 premium 4' lamps (F32T8/835) | 86 | Electronic | General lighting. The lowest cost and most efficient system available. Dimmable. | Not for general exterior lighting; not for very high spaces. |
| 87 | T-8 premium 8' lamps (F96T8/835) | 86 | Electronic | General commercial and institutional lighting. | 8' long lamps generally best in large spaces only. |
| 81 | T-5HO high output 4' lamps (F54T5/835) | 86 | Electronic | Indirect office lighting; high ceiling industrial lighting and specialty applications such as coves and wallwash. Dimmable. | Very bright lamps should not be used in open fixtures unless mounted very high. |
| 80 | Metal halide lamps, pulse start, M141 (1000 watt class) | 65 | Magnetic CWA | Very high bay spaces such as sports arenas, stadiums, and other locations above 30' | Very long warm up and restrike times prevent rapid switching and dimming |
| 79 | T-8 premium "U"-bent lamps (F32T8/U/835) | 86 | Electronic | Recessed commercial lighting. Dimmable. | More expensive than straight lamps. |
| 78 | T-5 twin tube ("biax") 40-50 watt (FT40T5/835) | 82 | Electronic | General commercial and institutional lighting; track mounted wallwash and display lighting. Dimmable. | More expensive than straight lamps – can be too bright in open fixtures. |
| 78 | Metal halide lamps, pulse start, 450 watt class | 65 | Magnetic CWA | General high bay lighting for gyms, stores, and other applications to about 30'; parking lots | Very long warm up and restrike times prevent rapid switching and dimming |
| 75 | T-8 premium 2' lamps (F17T8/835) | 86 | Electronic | General commercial lighting. Dimmable. | Not for general exterior lighting; not for very high spaces. |
| 67 | Metal halide lamps, pulse start, M137 (175 watt class) | 65 | Magnetic CWA | Parking lots and site roadway lighting | Very long warm up and restrike times prevent rapid switching and dimming |
| 64 | Metal halide lamps, pulse start, M142 (150 watt class) compact T-6 high CRI | 85 | Electronic (CWA magnetic <60 MLPW) | Track and recessed mounted display lighting | May not be suitable for general illumination due to lamp cost; very long warm up and restrike times prevent rapid switching and dimming |
| 63 | Metal halide lamps, pulse start, ED-17 M140 (100 watt class) high CRI | 85 | Electronic or magnetic HX or CWA | Recessed and track mounted display lighting | May not be suitable for general illumination due to lamp cost; very long warm up and restrike times prevent rapid switching and dimming |
| 62 | Compact fluorescent 18-42 watt triple | 82 | Electronic | Downlights, sconces, wallwashers, pendants and other compact lamp locations; can also be used outdoors in most climates. Dimmable. | Modest efficacy is still far better than incandescent |
| 30 | Halogen infrared reflecting lamps in PAR-30, PAR-38, MR16 and T-3 shapes | 100 | None required | Localized accent lighting and where full range, color consistent dimming is absolutely required such as fine restaurants, hotels, high end retail, etc | Cost effective technology must be used in limited amounts |

*Mean lumens per watt vary depending on specific ballast. Values given are optimum lamp-ballast combinations, and other combinations may be lower.

## Luminaires

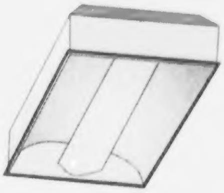
Luminaires (light fixtures) generally consist of lamps, lamp holders or sockets, ballasts or transformers (where applicable), reflectors to direct light into the task area, and/or shielding or diffusing media to reduce glare and distribute the light uniformly. There is an enormous variety of luminaire configurations. This section briefly outlines some of the more important types for school lighting design. For more information about these luminaire types, refer to the on-line Appendix that supports the Best Practices Manual.



*Recessed Fluorescent Lens Troffer*

### Recessed Luminaires

Recessed luminaires represent a large segment of the overall luminaire market. There are two basic variations, lay-in troffers and downlights. The primary use of lay-in troffers is as a direct general light source. Downlights are relatively compact luminaires used for wall washing, accent lighting, supplemental general or task illumination, as well as for lower levels of ambient illumination.



*Indirect Troffer*

*Indirect Linear Fluorescent Luminaire*

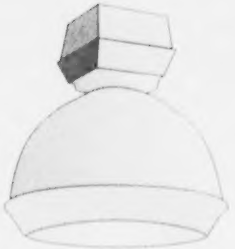
A relatively new type of recessed luminaire is the "indirect troffer." It is meant to soften the distribution pattern of a direct distribution luminaire without losing lighting uniformity. However, in many cases the surface brightness of the exposed reflector is actually higher than that of a standard troffer. Use them with caution, and don't use them in larger building spaces such as classrooms and open offices.

### Suspended Classroom Luminaires

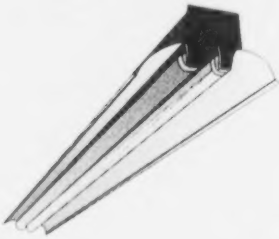
Suspended indirect or direct/indirect luminaires are the preferred luminaires for lighting classrooms. They are also appropriate for offices, administrative areas, library reading areas and other spaces. Typically these luminaires employ T-8, T-5, or T-5HO lamps, and mount in continuous row configurations. See Guideline EL1 – Pendant Mounted Lighting.

### Suspended High Ceiling Luminaires

Both fluorescent and HID suspended luminaires are useful for illuminating building spaces such as gymnasiums and other high-ceilinged spaces. HID luminaires can be classified as either high bay (>25 ft mounting height) or low bay, depending on the configuration. Compact fluorescent high-bay luminaires are also available to light high ceiling spaces. They employ up to eight compact fluorescent lamps to approximate the light output of an HID luminaire, while allowing for additional control flexibility. See Guideline EL5 – Gym Lighting. Linear hooded industrial fluorescent luminaires can be extremely effective at lighting high ceiling spaces.



*Low-bay HID Luminaire*



*Hooded Industrial Fluorescent Luminaire*

### Surface-mounted Luminaires

Surface-mounted fluorescent, compact fluorescent and HID luminaires are valuable for wall and ceiling mounting situations, particularly when ceiling access is a problem.

### Specialty Luminaires

Several specialty luminaires are available for specific school lighting applications. These include specialty wall wash luminaires to illuminate blackboards, task lighting luminaires to supplement general illumination, wet location luminaires for exterior areas open to the elements, and high-abuse luminaires designed to withstand vandalism in school and other institutional environments.

### Exit Signs

Numerous exit sign configurations are available for schools. LED exit signs offer the best alternatives for minimizing energy use and maintenance. However, compact fluorescent exit signs may be preferable in some instances when higher surface brightness or an additional downlight component is desired. Avoid self-luminous atomic exit signs because they are difficult to dispose of, and may not provide adequate surface luminance.

## Lighting Controls

Lighting controls are critical for minimizing lighting energy use and maximizing space functionality and user satisfaction. Control techniques ranges from simple to extremely sophisticated. Lighting control strategies are most successful when people can easily understand their operating characteristics. Another critical factor is the proper commissioning of lighting control systems so that they operate according to design intent. Finally, regularly scheduled maintenance of control equipment will improve the long-term success of the system. Poorly designed, commissioned or maintained automatic lighting controls can actually increase lighting energy use, and cause user dissatisfaction.

This section provides a brief overview of lighting control hardware available for school applications. For more detailed information, as well as application tips for effective use of lighting controls, see the on-line Appendix that supports the Best Practices Manual.

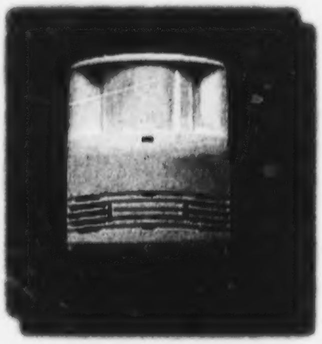
### Switches

Manual switches are the simplest form of user-accessible lighting control. Minimal compliance with Title 24 requires individual manual switching for each separate building space. Bi-level switching is also required in spaces larger than 100 $ft^2$ with a connected lighting load greater than 0.8 $W/ft^2$. Additional switching requirements are triggered by daylit spaces.

Manual switches are especially valuable in daylit building spaces because they allow people to turn off electric lights when daylight is adequate. Manual switches should also be installed in spaces with occupancy sensors. This increases the energy savings of occupancy sensor controls by allowing people to turn off the lights when they are not needed.

### Occupancy Sensors

Occupancy sensors employ motion detectors to shut lights off in unoccupied spaces. The primary detection technology can be either passive infrared (PIR) or ultrasonic. Some sensors employ both passive infrared and either ultrasonic or microphonic detection. Mounting configurations include simple wall box sensors appropriate for small spaces such as private offices, and ceiling- or wall-mounted sensors that provide detection of areas up to 2,000 $ft^2$.



*Dual Technology Occupancy Sensor*

Occupancy sensors are most effective in spaces that are intermittently occupied, or where the lights are likely to be left on when unoccupied. The best school applications include classrooms, private offices, restrooms and storage areas. Use occupancy sensors in combination with manual overrides whenever possible to maximize energy savings, space flexibility, and occupant satisfaction. Including manual off override to the control scheme allows the teacher to turn the lights off for video presentations or other situations requiring the lights to be off. See Guideline EL4 – Lighting Controls for Classrooms.

### Time Controls

Digital Time Switch

Time controls save energy by reducing lighting time of use through preprogrammed scheduling. Time clocks comply with the California Building Code requirements for whole building shut-off. Time control equipment ranges from simple devices designed to control a single electrical load to sophisticated systems that control several lighting zones.

Time controls make sense in applications where the occupancy hours are predictable, and where occupancy sensor automatic control is either impractical or undesirable. Candidate building spaces include classrooms, offices, library stacks (local digital time switches), auditoriums, and exteriors. Keep in mind that Title 24 requires manual override of time clock control whenever they are installed to comply with whole building shut off.

### Energy Management Systems (EMS)

Typically when lighting is controlled through an EMS it is via a time clock. However, many building operators take advantage of the built-in EMS functions to monitor lighting usage on a space-by-space basis. EMS control of lighting systems may also allow building operators to shed non-essential lighting loads during peak demand periods.

### Manual Dimmers

Next to standard wall switches, manual dimmers are the simplest of lighting control devices. Manual dimmers serve two important functions. First, dimming lights reduces lighting demand and energy usage. With incandescent and halogen sources, there is the additional benefit of extended lamp life. However, more importantly, dimmers allow people to tune the lights to optimum levels for visual performance and comfort.

Consider manual dimmers (combined with dimming ballasts, where applicable) for many school building spaces, including classrooms, computer classrooms and office spaces. A/V rooms *require* manual dimming to function properly.

### Photoelectric controls

Photoelectric control systems employ a photosensor and logic controller to control lights in daylit spaces, such as classrooms and corridors. The logic controller processes a signal from the photosensor and sends a dimming or switching signal to the lighting circuit based on the monitored light level. Open-loop systems "see" only daylight, while closed-loop systems monitor both daylight and the light emitted by the luminaires they control.

Successful employment of photoelectrically controlled lighting systems requires careful design, installation, and commissioning, as well as a commitment to the long-term maintenance of the system. Without these elements, energy savings are rarely sustainable.

## Analysis Tools

Several high quality analysis tools are available to help professionals design lighting systems. The simplest of these programs provide rudimentary zonal cavity calculations to predict average horizontal footcandles, while the most sophisticated tools can handle extensive calculations and produce realistic renderings.

Many of the major luminaire manufacturers offer standard computational software that can predict the performance of their (or other's) luminaires in typical lighting designs. Typically, these programs can calculate horizontal and vertical illuminance for a number of points within the space. Some can produce rudimentary renderings, as well. Most can export output to AutoCAD.

Companies that specialize in lighting software offer the most sophisticated lighting software packages. These products are typically much more robust than the manufacturer-provided packages, and can handle more complex problems, such as surface luminances, daylight effects, irregularly shaped rooms, and high resolution rendering.

Sample Manufacturers and products:

- AGI
- LCA (LitePro)
- Lightolier (Genesys)
- Lightscape
- Lithonia (Visual)
- LumenMicro

## Applicable Codes

Several codes or standards affect the design and installation of lighting equipment. This section outlines some of the relevant considerations.

### ADA

The Americans with Disabilities Act (ADA) affects the selection and installation of lighting equipment. For the most part, ADA only affects wall-mounted luminaires, which cannot protrude more than 4 in. when mounted below 80 in. above the finished floor.

### Egress and Emergency Lighting

Emergency egress and exit lighting requirements are mandated in the UBC, NEC, and NFPA codes. Lighting design must address the minimum lighting levels for egress, as well as include the necessary exit signage for exiting. Most counties and municipalities require at least minimal compliance with NEC, and some may require additional measures.

### UL Listing

According to the NEC, all luminaires used in construction must be listed by an approved testing agency, such as Underwriters Laboratory (UL). The designer must be sure that all luminaires specified are properly listed by a testing agency recognized by the local electrical inspector. In addition, there are distinctions that need to be made for special applications, such damp, wet, and hazardous locations.

### California Building Code

All school buildings must comply with the State of California's *Energy Efficiency Standards for Nonresidential Buildings* (Title 24). A significant portion of Title 24 is devoted to lighting systems. The standards require several mandatory measures for lighting systems including:

- Area controls
- Bi-level switching
- Additional switching in daylit zones
- Certification of ballasts and luminaires
- Automatic shut-off for buildings larger than 5,000 $ft^2$
- Automatic control for exterior lighting
- Certification of controls

Title 24 also has prescriptive requirements for lighting power. As of 1998, the lighting power limits for applicable school building spaces (Area Category Approach) are as follows:

*Table 13 – California Lighting Power Limits for Schools, Whole Area Method*

| *Area Type* | *Allowed Lighting Power ($W/ft^2$)* |
|---|---|
| Classrooms, lecture halls, vocational rooms | 1.6 |
| Offices | 1.3 |
| Corridors, restrooms, stairs, & support areas | 0.6 |
| Library reading areas | 1.2 |
| Library stacks | 1.5 |
| Multipurpose centers | 1.6 |
| Auditoriums | 2.0 |
| Gymnasiums | 1.0 |
| Locker rooms | 0.9 |
| Kitchens, food preparation areas | 1.7 |
| Reception lobbies, waiting areas | 1.1 |
| Electrical & mechanical rooms | 0.7 |
| Storage rooms, closets | 0.6 |

## Resource Efficiency

The overall value of energy-efficient lighting systems is reduced energy use, less air pollution, lower maintenance costs, and reduced material requirements. Properly designed lighting systems minimize lighting demand and energy use. In addition, effective use of lighting controls can extend the service life of lighting equipment, reducing maintenance costs and replacement equipment inventories.

Although lighting's environmental impacts primarily relate to energy performance and enhanced indoor environmental quality, other environmental considerations include materials efficiency and pollution prevention during manufacturing:

- *Materials efficiency:* Metal components of lighting fixtures can be recycled, and whole fixtures can be salvaged during building deconstruction. These fixtures can be refurbished and reused. The metal components of fixtures may include recycled content, although data is not readily available as to the amount.

- *Pollution prevention:* Powder finishes on luminaires may pose a problem during manufacture, but information about these finishes is not readily available.

## Mercury and Lamp Recycling

Mercury in fluorescent lamps is a serious issue that has been documented and is being addressed by the lighting industry. Mercury is a toxic element and there are significant concerns about mercury being emitted into the atmosphere or released into groundwater when fluorescent lamps are disposed of.

Fluorescent lamps operate by electrically exciting mercury gas so that it emits ultraviolet light, which in turn causes the phosphor coating to fluoresce and emit light. On average, fluorescent lamps contain approximately 23 milligrams of mercury per four-foot lamp. Recent developments in lamp coating technology have resulted in low mercury lamps that contain around 10 milligrams per lamp. There is a relationship, however, between lamp life and mercury content.

The U.S. Environmental Protection Agency has declared that lamps containing mercury are hazardous materials requiring special handling. This applies to all fluorescent lamps, and in some cases may also be defined to include HID lamps. Spent lamps may be disposed of in special landfills; however, it is much more ecologically responsible to recycle them. Most lamps used in schools can be completely recycled by a number of different recycling companies. Current costs for recycling lamps average about $0.06 per linear foot. When preparing a maintenance plan for a lighting system, it is advisable to include a lamp recycling procedure.

School districts should be good environmental stewards and engage in recycling programs for fluorescent lamps. For demolition and renovation projects, recycling of lamps should be required where local recycling options are available.

## Maintenance

Maintaining lighting systems is critical to the sustainable performance, lighting quality, and energy efficiency of lighting systems. Establishing proper maintenance procedures is as much a responsibility of the designer as it is of the custodian who changes lamps. A good lighting maintenance plan should be included within the building specifications.

### Luminaire Cleaning and Troubleshooting

Thoroughly clean luminaires at regular intervals. Regular maintenance ensures that the lighting system will continue to perform as designed, thereby maximizing lighting quality and space appearance. When cleaning luminaires, maintenance personnel should also check for and replace any broken or malfunctioning equipment, such as lenses, louvers, and ballasts.

### Group Relamping

Lighting systems perform best when they are maintained at regular intervals. Group relamping is a maintenance strategy aimed at maximizing lighting system performance and maintenance economy by changing out all lamps at regular intervals, as opposed to relamping only when lamps have burned out. In the long run, group relamping reduces the cost of maintaining lighting systems through simple economy of scale. Furthermore, relamping luminaires at regular intervals maintains light levels and lighting quality according to design intent, and establishes good lighting maintenance procedures. For best economy, group relamping should be combined with luminaire cleaning and troubleshooting.

### Specifications

Designers of school lighting systems have a number of specification tools available to promote proper maintenance and reduce maintenance costs. For example:

- Specify premium T-8 lamps whenever possible to extend lamp life by 20%.
- Try to limit the number of different lamp types specified. This will simplify maintenance and allow for reduced lamp backup stocks.
- Include specification language that requires the contractor to supply the owner with manuals for occupancy sensors and other automatic control hardware.
- Include a maintenance manual in the lighting specification (see below).

### Maintenance Manual

Include a detailed maintenance package with the building specifications. At a minimum the package should contain the following:

- As-built plans showing the installed lighting systems
- Luminaire schedule that includes detailed lamp and ballast information
- Luminaire cut sheets
- Lamp inventory list, including recommended stocking quantities
- Manufacturer data for all lighting controls, including operating documentation and tuning procedures
- Procedures for maintaining lighting controls
- Luminaire cleaning and troubleshooting procedures
- Group relamping procedure
- Lamp recycling plan and contacts

## Commissioning

All automatic lighting control systems must be tuned after installation to ensure optimal performance and energy efficiency. Malfunctioning automatic control systems waste energy and will disturb students, teachers and staff. Building specifications should include a commissioning plan that identifies the commissioning agent and details the required procedures. The commissioning plan should include the following items:

*Dimmed Fluorescent Lamps:* Fluorescent lamps must be seasoned for 100 hours or more prior to being dimmed, when dimming controls are employed. Dimming the lamps prior to this "burn in" period can significantly reduce lamp life.

*Occupancy Sensor Sensitivity/Time Delay:* Motion sensors must be adjusted to make certain that they only sense motion in the controlled space. Motion in adjoining spaces can cause false triggering or cause the lights to remain on needlessly, thereby wasting energy. Similarly, sensors must not turn lights off when spaces are occupied. An additional adjustment on sensors controls the time delay period between last detection and lights off. In most cases, this period can be set to 10 minutes for good results.

*Photosensors:* Photosensors designed for use in open loop daylighting control systems must be mounted so that they cannot detect the lights they control. This may require some tweaking or relocation of the unit after installation. Consult the manufacturer's recommendations for proper procedures for commissioning photosensor devices.

*Dimming Controllers:* Dimming controllers for lighting systems should be tuned such that illuminance at the high dimming range will not exceed design parameters. This is a relatively easy procedure on most dimming boards, requiring a simple adjustment. Similarly, the commissioning agent can also set the minimum light level.

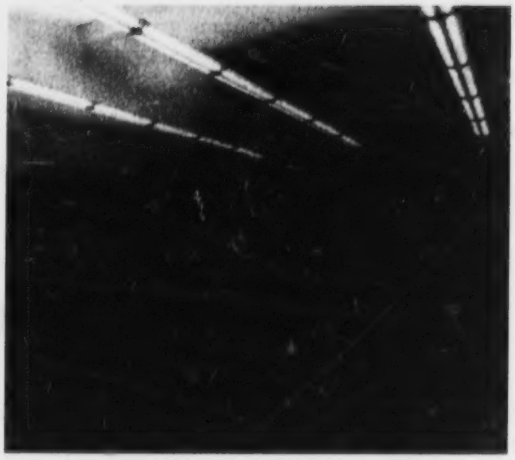
*Relay Controllers:* If a stepped lighting control system is employed for daylight harvesting, it is important to adjust the deadband between the on and off switching thresholds so that the system does not cycle on cloudy days. Continuous on-off cycling is annoying to building occupants and reduces lamp life.

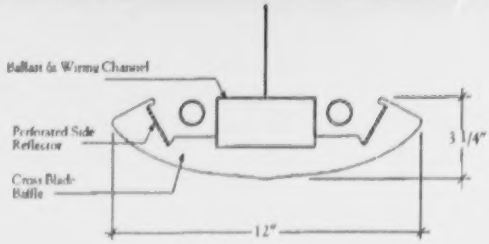
## Guideline EL1: Pendant Mounted Lighting

### Recommendation

In rooms having a ceiling at least 9'-6" high, utilize suspended fluorescent lighting having either

- A semi-indirect or indirect distribution and at least 85% luminaire efficiency, using T-8 premium lamps and electronic ballasts and a connected lighting power of 1.1 to 1.3 watts per square foot; or
- Direct/indirect distribution and at least 75% luminaire efficiency, using T-8 premium lamps and electronic ballasts and a connected lighting power of 0.9 to 1.1 watts per square foot.





| Applicable Spaces | |
|---|---|
| Classrooms | ■ |
| Library | ■ |
| Multipurpose / Cafeteria | ■ |
| Gym | ☐ |
| Corridors | ▨ |
| Administration | ■ |
| Toilets | ☐ |
| Other | ☐ |

| Climates | |
|---|---|
| South Coast | ■ |
| North Coast | ■ |
| Central | ■ |
| Mountains | ■ |
| Desert | ■ |

| When to Consider | |
|---|---|
| Programming | ▨ |
| Schematic | ■ |
| Design Dev | ▨ |
| Contract Docs | ☐ |
| Construction | ☐ |
| Commissioning | ☐ |
| Operation | ☐ |

### Description

There are several appropriate types of suspended fluorescent luminaires, which are classified according to the fraction of uplight and downlight.

- Direct/indirect luminaires are designed for general classroom use, so that the ceiling, walls and floor are all illuminated relatively evenly.
- Indirect luminaires were originally designed for office lighting, and are slightly preferable in classrooms with significant computer work.

Most direct/indirect luminaires are rated according to the percentages of uplight and downlight. In a direct/indirect luminaire, the amount of uplight and downlight is roughly the same. The type of luminaire shown here is 65% uplight, and 35% downlight. While a light colored ceiling is preferred to take advantage of the uplight, a direct/indirect lighting system can be used with light colored wood or other materials. The suspension length of direct/indirect lighting is less critical than for indirect lighting.

In an indirect luminaire, the amount of uplight is at least 90%. The downlight is generally intended to create a sense of brilliance, but most of the illumination in the room is caused by reflected light from the ceiling. Indirect lighting requires a light colored ceiling and a minimum suspension length of 12", with 18" or more strongly preferred.

In both cases affordable luminaires are made of steel bodies and steel or plastic louvers. More sophisticated luminaires employ extruded aluminum housings, but this generally incurs significant increased cost. Likewise, T-5 and T-5HO lighting systems will cost more than T-8, and can create more glare from the direct lighting.

### Applicability

Pendant mounted lighting is appropriate for all classrooms, libraries, multi-purpose spaces, and administration spaces.

250 A

## Applicable Codes

See the Applicable Codes section in the overview. The California Building Code limits the amount of lighting power per classroom to 1.6 w/ft² (1999), which is satisfied by this guideline. Title 24 also requires switching (see Guideline EL4 - Lighting Controls for Classrooms).

## Integrated Design Implications

Suspended lighting systems can work well with almost all ceiling systems that are at lease 9 ft 6 in. high. However, dark ceilings such as dark stained wood or dark colored paint must be avoided. For direct/indirect luminaires, ceilings should be light colored; for indirect fixtures, ceilings must be white or off white, as should upper walls. Should the room have an extremely high ceiling, such as with a sawtooth clerestory, a direct/indirect luminaire with a greater percentage of downlight (50% or more) should be used.

## Costs

Suspended lighting systems costs are shown in Table 14. Suspended lighting systems provide a high degree of cost effectiveness in most applications. Non-dimming, indirect steel luminaires are the lowest cost, but optimum solutions are generally steel luminaires with steel or plastic louvers with 35%-50% downlight.

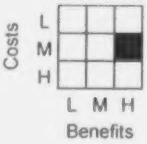


*Table 14 – Indirect/Direct Lighting Cost*

| Lighting System Type | Cost per lineal foot, installed* |
|---|---|
| Steel indirect luminaires, 90%+ uplight, T-8 lamps, non-dimming | $35 |
| Steel direct/indirect luminaires, plastic louvers, 65% uplight, T-8 lamps, non-dimming | $40 |
| Steel direct/indirect luminaires, steel louvers, 50% uplight, T-8 lamps, non-dimming | $45 |
| Extruded aluminum luminaires, parabolic louvers, 75% uplight, T-8 lamps, non-dimming | $50 |
| Add for dimming ballasts using standard 0-10 volt type | $12-15 |

*Approximate cost to Owner, including labor, materials, overhead, profit, and costs of construction for lighting, including luminaires, lamps, and suspension hardware. Includes connecting luminaire to branch circuit. Controls and branch circuit costs not included. Based on July 2000 prices. Costs can vary depending on market conditions.

## Benefits

Direct/indirect lighting systems generally offer an optimum combination of efficiency and visual comfort, and make excellent use of the low-cost, widely used T-8 lamp system. Systems operating at about 1.0 w/ft² will generate between 40 and 50 footcandles, maintained average, with excellent uniformity. Indirect lighting systems are generally less efficient, requiring 1.1-1.2 w/ft² to achieve 40 to 50 footcandles.

## Design Tools

A modern lighting point calculation program using radiosity or ray tracing methods should be used. However, minimally acceptable results will be obtained using lumen method or watts-per-square-foot methods. See also Analysis Tools in the Overview of this chapter.

## Design Details

This type of lighting provides good general lighting throughout the room and is suitable for most types of classroom work. Some types of direct/indirect lighting are optimized for computer CRT work, although they tend to be expensive. It may be necessary to provide separate chalkboard illumination, especially if the suspended lighting system is manually dimmed. Be certain to employ premium T-8 lamps with 835 or 841 color, rated 24,000 hours. For non-dimming applications, luminaire light and power can be varied through choice of ballast factor. Use Table 11 and specify ballasts accordingly.

A typical classroom (below) with two rows of two lamp suspended luminaires. Not including daylight contribution, most of the room is between 40 and 60 footcandles at 0.9 W/ft². A slight increase in power will result in a proportional increase in light level; at 1.1 w/sf, the light levels will range between 49 and 73 footcandles.

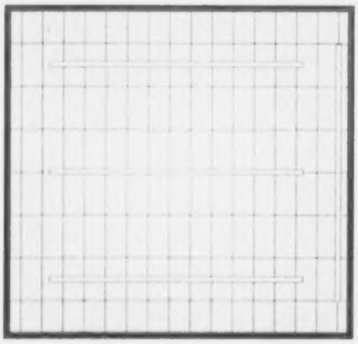


*Figure 3 – Classroom Pendant Mounted Lighting Design*

*This classroom design uses three rows of suspended fluorescent luminaires.*
*An optional blackboard light can be mounded at the teaching wall.*

### Operations and Maintenance

These lighting systems rarely need maintenance. As with all fluorescent systems, lamps should be replaced at approximately 12,000-16,000 hours of operation, which with normal school use could be as seldom as every 6 years. Luminaires should be cleaned annually. Open louvered luminaires, especially using plastic louvers, require less cleaning and are the most tolerant of poor maintenance and abuse.

### Commissioning

None other than preconditioning of lamps in dimming applications

### Example

Windsor High School, Windsor CA
Windsor Unified School District
Quattrocchi / Kwok Architects

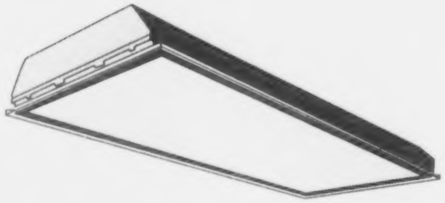
### References and additional information

Readers may wish to consult the *Advanced Lighting Guidelines* and the IESNA *Lighting Handbook*. Also, see *IESNA RP-3-00: Lighting for Educational Facilities*.

# Guideline EL2: Recessed Lighting

## Recommendation

This recommendation is only for spaces having a low ceiling where pendant mounted lighting is inappropriate or when the budget is limited. Use recessed fluorescent lens troffers having at least 78% luminaire efficiency, using T-8 premium lamps and electronic ballasts, and a connected lighting power of 0.9 to 1.1 watts per square foot.



## Description

Fluorescent troffers are designed to "lay in" in place of an acoustical tile in grid tee-bar ceiling systems. The most common and cost effective size is 2' x 4'; less common sizes include 2' x 2' and 1' x4'. Inside the box, there are two T-8 lamps, and the interior reflector should be either high reflectance white paint or highly polished ("specular") silvered coating or aluminum. Silvered coating increases the cost considerably but also increases efficiency to over 85%. The lens should be an industry standard "Pattern 12" prismatic acrylic lens, with a minimum lens thickness of .125" for durability and appearance.

| Applicable Spaces | |
|---|---|
| Classrooms | ■ |
| Library | ■ |
| Multipurpose / Cafeteria | ■ |
| Gym | □ |
| Corridors | ▨ |
| Administration | ■ |
| Toilets | ▨ |
| Other | ■ |

| | Climates |
|---|---|
| ■ | South Coast |
| ■ | North Coast |
| ■ | Central |
| ■ | Mountains |
| ■ | Desert |

| When to Consider | |
|---|---|
| Programming | ■ |
| Schematic | ■ |
| Design Dev | ■ |
| Contract Docs | □ |
| Construction | □ |
| Commissioning | □ |
| Operation | □ |

The luminaires can be laid-out in rows, although for classrooms many architects prefer a "doughnut" configuration. See the examples, below.

There are a number of variations of troffers. These include:

- Quality or price class. A "specification grade" troffer is generally deeper, heavier gauge metal and costs more. A basic troffer works just as well, but it is flimsier.
- Door type. A flat steel door with butt joints costs the least; a regressed aluminum door with mitered corners costs quite a bit more.
- "Static", meaning that the luminaire is basic and enclosed, "heat extraction" meaning the luminaire is designed to draw heat through the luminaire and into the ceiling plenum above, and "air handling" in which the luminaire can be connected to special HVAC supply or return devices. The cost of HVAC attachments is high, and they do not eliminate the need for conventional HVAC diffusers and grilles.

Lens troffers do not illuminate the ceiling and upper walls well, and from a lighting quality standpoint they are considered marginal. They are also essentially the same luminaire style as used in virtually every institutional building, contributing to an ordinary, cheap looking appearance.

## Applicability

Recessed lighting is appropriate for all classrooms, libraries, multi-purpose spaces, and administration spaces.

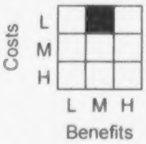
## Applicable codes

The National Electric Code (NEC) usually governs the electrical portion of lighting installations. Some cities have unique electrical codes, but most adopt the NEC. The energy considerations of lighting fall under California Title 24 (or similar codes in other states). Title 24 limits the amount of lighting power per classroom to 1.6 w/ft$^2$ (1999), so this recommendation exceeds code limits by a considerable amount. Title 24 also requires switching (see Guideline 4).

## Integrated Design Implications

This type of lighting should only be used in flat acoustic tile ceilings, and then only when ceiling height and/or budget prevents consideration of other options.

## Costs



Recessed lighting systems will cost about $120 per luminaire[8] for basic, white interior luminaires with .125" lens, two premium T-8 lamps, and electronic ballast. A dimming ballast will add about $40-$50 to each luminaire.

## Benefits

Troffer lighting systems generally offer excellent efficiency, but with some loss of visual comfort. They make excellent use of the low-cost, widely used T-8 lamp system. Systems operating at about 1.0 w/sf will generate between 50 and 60 footcandles maintained average, with very good uniformity.

## Cost Effectiveness

Lens troffer lighting systems are extremely low cost, but their inexpensive appearance can be a drawback.

## Design Tools

A modern lighting point calculation program using radiosity or ray tracing methods should be used. However, minimally acceptable results will be obtained using lumen method or watts-per-square-foot methods.

## Design Details

This type of lighting provides general lighting throughout the room and is suitable for most types of classroom work. However, lens troffers are not recommended for computer workspace. Separate chalkboard illumination is usually not required. Be certain to employ premium T-8 lamps with 835 or 841 color, rated 24,000 hours.

Luminaires need to be restrained in case of an earthquake. In general, this means that each luminaire must be hung from the structure with hanger wires independent of the ceiling system.

For non-dimming applications, luminaire light and power can be varied through choice of ballast factor. Use Table 11 and specify ballasts accordingly.

A typical classroom (bottom) with a "doughnut" pattern of two lamp troffers. Not including daylight contribution, most of the room is between 70 and 80 footcandles at 1.2 w/sf.

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[8] Approximate cost to Owner, including labor, materials, overhead, profit, and costs of construction for lighting, including luminaires, lamps, and suspension hardware. Includes connecting luminaire to branch circuit. Controls and branch circuit costs not included. Based on July 2000 prices. Costs can vary depending on market conditions.

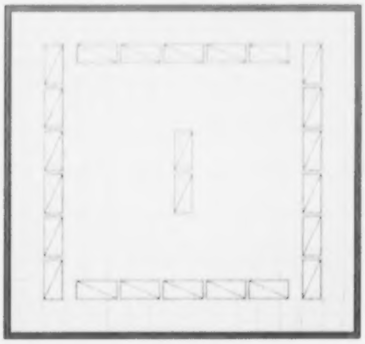


Figure 4 – Classroom Recessed Lighting Design

*This design uses two-lamp troffers to provide good vertical illumination and uniform horizontal illumination. The lighting power density is approximately 1.25 W/ft², using electronic ballasts with a low ballast factor.*

### Operations and Maintenance

These lighting systems rarely need maintenance. As with all fluorescent systems, lamps should be replaced at approximately 12,000-16,000 hours of operation, which with normal school use could be as seldom as every 6 years. Luminaires should be cleaned annually. Lensed luminaires require periodic cleaning and are occasionally abused. Lens replacement is relatively cheap and an acceptable condition even in applications where the designer expects poor maintenance and abuse.

### Commissioning

None other than preconditioning of lamps in dimming applications.

### Example(s)

### References and additional information

Readers may wish to consult the *Advanced Lighting Guidelines* and the IESNA *Lighting Handbook*. Also, see *IESNA RP-3-00: Lighting for Educational Facilities*.

# Guideline EL3: Surface Mounted Lighting

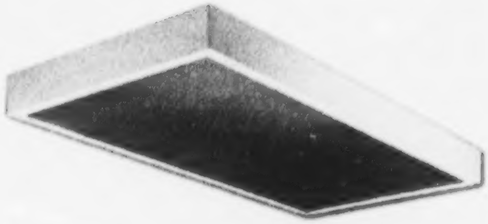
## Recommendation

This recommendation is for rooms having a ceiling no more than 12' high, that, for whatever reason, may not have recessed or suspended lighting systems. There are several possible circumstances:

- Ceiling height is 8' 6" or less, preventing use of suspended luminaires
- The ceiling cavity is impenetrable, such as due to the presence of asbestos or roof insulation
- The design of the space employs a hard ceiling surface, such as wood, that has a moderate reflectance

There are two good choices.

1. Use short stem-mounted semi-direct fluorescent luminaires having at least 65% efficiency, using T-8 premium lamps and electronic ballasts and a connected lighting power of 1.1 to 1.2 watts per square foot
2. Use surface-mounted fluorescent lens troffers having at least 78% efficiency, using T-8 premium lamps and electronic ballasts and a connected lighting power of 0.9 to 1.1 watts per square foot



| Applicable Spaces | | Climates | | When to Consider | |
|---|---|---|---|---|---|
| Classrooms | ■ | South Coast | ■ | Programming | ■ |
| Library | ■ | North Coast | ■ | Schematic | ■ |
| Mulit-Purpose / Cafeteria | ■ | Central | ■ | Design Dev | ■ |
| Gym | ☐ | Mountains | ■ | Contract Docs | ☐ |
| Corridors | ▨ | Desert | ■ | Construction | ☐ |
| Administration | ■ | | | Commissioning | ☐ |
| Toilets | ▨ | | | Operation | ☐ |
| Other | ■ | | | | |

## Description

Surface-mounted semi-direct luminaires are versions of direct/indirect luminaires designed for short stem mounting. In general, this means a luminaire that is mounted very close to the ceiling, no more than 6" or so from the ceiling to the lowest part of the luminaire. A small percentage of uplight illuminates the adjacent ceiling with a minimum amount of light to prevent a hot spot. These two T-8 lamp luminaires require some form of downlight shielding. Louvers and lenses are the two most likely choices.

In general, the layout of surface-mounted semi-direct luminaires will be similar to the layout for suspended lighting systems shown in Guideline One. This will result in higher light levels with a slight sacrifice in lighting quality.

Surface-mounted direct luminaires are similar to troffers, but within finished box enclosures. The most common and cost effective size is 2' x 4'; less common sizes include 2' x 2' and 1' x4'. As with recessed troffers, inside the box, there are two T-8 lamps, and the interior reflector should be either high reflectance white paint or highly polished ("specular") silvered coating or aluminum. The lens should be a Pattern 12 prismatic acrylic lens, with a lens thickness of .125". Other variations applicable to troffers, such product grade and door type, also apply.

## Applicability

### Applicable codes

The National Electric Code (NEC) usually governs the electrical portion of lighting installations. Some cities have unique electrical codes, but most adopt the NEC. The energy considerations of lighting fall under California Title 24 (or similar codes in other states). Title 24 limits the amount of lighting power per classroom to 1.6 W/ft² (1999), so this recommendation exceeds code limits by a considerable amount. Title 24 also requires switching (see Guideline 4).

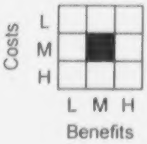
Suspended luminaires need to be restrained in case of an earthquake. For short stem luminaires, the luminaire usually cannot swing, but support independent of the ceiling system is still needed.

### Integrated Design Implications

This type of lighting should only be used in very specific applications. Guidelines One and Two should be pursued first; this Guideline should only be pursued when ceiling issues prevent consideration of other options.

### Costs[9]

Surface mounted lighting systems will cost about $200 per luminaire for basic, lensed white enclosed direct luminaires with .125" lens, two premium T-8 lamps and an electronic ballast. Steel or aluminum surface luminaires will probably cost a bit more, roughly $240 each. A dimming ballast will add about $40-$50 to each luminaire.



### Benefits

Troffer lighting systems generally offer excellent efficiency, but with some loss of visual comfort. They make excellent use of the low-cost, widely used T-8 lamp system. Systems operating at about 1.0 w/sf will generate between 50 and 60 foot-candles maintained average, with very good uniformity.

### Cost Effectiveness

Surface mounted lighting systems are relatively expensive compared to recessed troffers and offer good value.

### Design Tools

A modern lighting point calculation program using radiosity or ray tracing methods should be used. However, minimally acceptable results will be obtained using lumen method or watts-per-square-foot methods.

### Design Details

This type of lighting provides general lighting throughout the room and is suitable for most types of classroom work. However, lensed luminaires are not recommended for computer workspaces. Separate chalkboard illumination is usually not required. Be certain to employ premium T-8 lamps with 835 or 841 color, rated 24,000 hours.

For non-dimming applications, luminaire light and power can be varied through choice of ballast factor. Use Table 11 and specify ballasts accordingly.

See Guidelines 1 and 2 for examples on using semidirect and surface-mounted direct luminaires in classrooms.

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[9] *Approximate cost to Owner, including labor, materials, overhead, profit, and costs of construction for lighting including luminaires, lamps, and suspension hardware. Includes connecting luminaire to branch circuit. Controls and branch circuit costs not included. Based on July 2000 prices. Costs can vary depending on market conditions.*

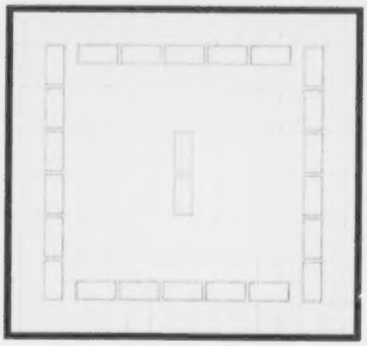


*Figure 5 – Classroom Surface Mounted Lighting Design*

*This design uses two-lamp troffers to provide good vertical illumination and uniform horizontal illumination. The lighting power density is approximately 1.25 W/ft², using electronic ballasts with a low ballast factor.*

## Operations and Maintenance

These lighting systems rarely need maintenance. As with all fluorescent systems, lamps should be replaced at approximately 12,000-16,000 hours of operation, which with normal school use could be as seldom as every 6 years. Luminaires should be cleaned annually. Lensed luminaires require periodic cleaning and are occasionally abused. Lens replacement is relatively cheap and an acceptable condition even in applications where the designer expects poor maintenance and abuse.

## Commissioning

No commissioning is needed, other than preconditioning of lamps for dimming applications.

## Example(s)

## References and additional information

Advanced Lighting Guidelines

IESNA Lighting Handbook

IESNA RP-3-00: Lighting for Educational Facilities

# Guideline EL4: Lighting Controls for Classrooms

## Recommendation

Depending on daylight availability and the audio-video needs of the classroom (including extensive computer work), the following recommendations should be followed.

| | Daylighted Classrooms | Minimum Daylighting |
|---|---|---|
| Audio Visual Needs | Dimming ballasts, automatic daylight sensing, manual dimming and manual override | Dimming ballasts, motion sensing, manual dimming and manual override |
| No Special Audio-Video Needs | Dimming ballasts, automatic daylight sensing and motion sensing with manual override | Motion sensing system with manual override |

## Description

Lighting controls can dramatically affect both the energy use of a lighting system and the usability of the lighting when the classroom is being used for audio-video or computer education.

As a minimum, all classrooms should employ motion sensors, preferably in conjunction with a switch that can turn lights off regardless of sensor "state". Most sensors are passive infrared and respond to the movement of warm bodies. Upper wall and corner sensors are the best choice, and dual mode sensors employing ultrasonic, microphonic or another form of backup sensing are strongly recommended. These types of sensors generally require a power pack (transformer-relay) that actually switches the circuit.

Wallbox sensors that replace wall switches are not a good choice for classrooms. For maximum flexibility, manual switches should be wired in series with the motion sensor relay so that lights can be turned off manually, regardless of whether there is motion in the room.

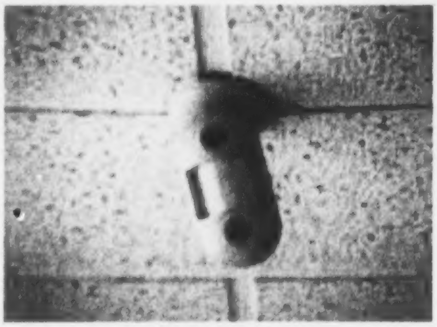


*Photo courtesy: Evan Lesley*

| Applicable Spaces | | Climates | | When to Consider | |
|---|---|---|---|---|---|
| Classrooms | ■ | South Coast | ■ | Programming | ☐ |
| Library | ▨ | North Coast | ■ | Schematic | ☐ |
| Mulit-Purpose / Cafetena | ☐ | Central | ■ | Design Dev | ■ |
| Gym | ☐ | Mountains | ■ | Contract Docs | ■ |
| Corridors | ☐ | Desert | ■ | Construction | ☐ |
| Administration | ■ | | | Commissioning | ☐ |
| Toilets | ☐ | | | Operation | ☐ |
| Other | ☐ | | | | |

The falling cost of dimming ballasts for T-8 lamps makes dimming possible for many projects. Dimming ballasts permit both manual dimming, permitting the teacher to adjust lighting levels, and automatic dimming, especially to respond to daylight. Ballasts should be specified in conjunction with an overall dimming system to ensure compatibility.

For spaces with daylight, automatic daylight sensors are recommended for lights near the window wall. "Open loop" sensors that are not affected by room light are strongly recommended.

For spaces with audio video needs that require manual dimming, a wall mounted dimmer controller should be used.

## Applicability

These lighting control strategies are appropriate for classrooms and some areas in administration spaces and libraries.

### Applicable codes

The National Electric Code (NEC) usually governs the electrical portion of lighting installations. Some cities have unique electrical codes, but most adopt the NEC. The energy considerations of lighting fall under California Title 24 (or similar codes in other states). Title 24 requires that all spaces have a switch with automatic shut-off. Installing a motion sensor meets this requirement.

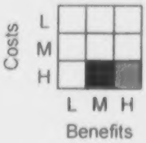
Title 24 also requires that luminaires in a daylit zone (area near window or skylight) have separate switching or dimming. If automatic daylighting dimming is not used, it will be necessary to switch the lights near the windows separately from the interior lights. See models, below.

Title 24 provides a controls credit" for automatic controls like motion sensors and daylight dimming. While no credit is given for small windows, a power credit of up to 40% is given for daylighting dimming in rooms with effective windows and skylights. In other words, a lighting system of 1000 watts is considered only 600 watts if controlled by a daylighting dimming system.

### Integrated Design Implications

Controls are essential in achieving the overall goal of reducing energy consumption.

### Costs



A pair of motion sensors and one power pack adds about $200* per classroom. Dimming ballasts add about $40-$50 per ballast, or up to $1200* per classroom. Automatic daylighting control without manual dimming adds about $200 per classroom, in addition to the costs of ballasts.

A control system that permits manual dimming in conjunction with motion sensing and daylighting will cost about $1000 per classroom[10] in addition to the costs of the dimming ballasts.

### Benefits

Each control element added saves energy. Depending on the operating months of the school, the quality of daylight, the climatic zone, and other factors, energy cost savings vary from good to dramatic.

### Cost Effectiveness

Controls are an evolving area of technology for buildings. At present, cost effectiveness is good, but costs remain relatively high.

- For motion sensing, cost effectiveness varies depending on the overall energy management skills of teachers and staff. People who are personally careful with energy outperform motion sensors, but for less well managed spaces, motion sensors are worthwhile.
- Daylight sensors and dimming ballasts are worthwhile if the daylighting is designed correctly.
- Systems employing manual dimming, daylighting and motion sensing are presently only cost effective if audio-video or computer requirements of the building use need to be met.

### Design Tools

There are very few useful design tools in this evolving field. The best information is usually obtained from controls manufacturers and their representatives.

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[10] Approximate cost to Owner, including labor, materials, overhead, profit, and costs of construction for lighting including luminaires, lamps, and suspension hardware. Includes connecting luminaire to branch circuit. Controls and branch circuit costs not included. Based on July 2000 prices. Costs can vary depending on market conditions.

### Design Details

- Use two dual-technology motion sensors, set in the corners of the classroom opposite the door. Wire the power for the lights in series with the sensors' transformer-relay and wall switche(s). Use one switch if automatic daylight controls are being used, and two switches if not.
- Use 0-10 volt dimming ballasts unless you are employing a complete system of control. 0-10 volt controls are the most universal at present.
- Use daylight sensors located within 5 feet of the window, and preferably, are not "closed loop" type.

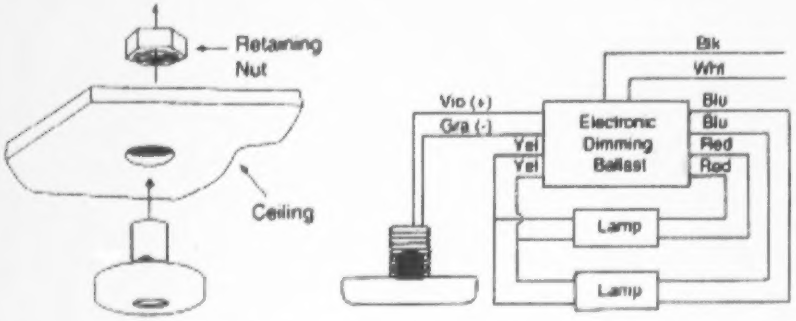


*Figure 6 – Ceiling Mounted Light Sensor*

*Sensor connects directly to the violet and gray terminals of industry standard 0-10 volt ballasts.*

### Operations and Maintenance

In operation, a properly commissioned system needs only periodic maintenance to ensure optimum performance. Refer to the manufacturer's recommended recalibration and cleaning cycle for sensors.

### Commissioning

Commissioning of motion sensor systems and daylighting controls is critical to their success. Systems that work properly will be left alone; systems that have false tripping and other unwanted behavior will end up disconnected or bypassed. Good rules of thumb:

- The sensitivity of motion sensors should be set according to the manufacturer's instructions. A proper setting will minimize false tripping and unwanted cycling. Because sensors are both physically and electronically adjustable, care should be taken to ensure the sensors are working as intended.
- The time-out setting of motion sensors is also critical. A setting too short may cause false tripping; a setting too long fails to save energy as well. A preliminary time out setting of 15 minutes is suggested as a compromise.
- Daylight sensor settings should be made and checked several times. Use a good light meter (Minolta TL-1 or better).

### Example(s)

### References and additional information

Readers may wish to consult the *Advanced Lighting Guidelines* and the IESNA *Lighting Handbook*. Also check out EPRI's *Controls: Patterns for Design* and *IESNA RP-3-00: Lighting for Educational Facilities.*

# Guideline EL5: Gym Lighting

Windsor High School Gym, Photo courtesy Quattrocchi / Kwok Architects

| Applicable Spaces | | Climates | | When to Consider | |
|---|---|---|---|---|---|
| Classrooms | ☐ | South Coast | ■ | Programming | ■ |
| Library | ☐ | North Coast | ■ | Schematic | ■ |
| Mulit-Purpose / Cafeteria | ☐ | Central | ■ | Design Dev | ■ |
| Gym | ■ | Mountains | ■ | Contract Docs | ■ |
| Corridors | ☐ | Desert | ■ | Construction | ■ |
| Administration | ☐ | | | Commissioning | ☐ |
| Toilets | ☐ | | | Operation | ☐ |
| Other | ☐ | | | | |

**Recommendation**

There are three choices for gym lighting:

1. **Metal Halide**. Employ metal halide industrial-style "high bay" luminaires over basketball court(s) volleyball area(s), gymnastics area(s) and other portions of the gymnasium where a high ceiling and structure must be maintained. The metal halide luminaires should employ 320 to 450 watt "pulse start" lamps and 277-volt reactor ballasts if possible. They will provide at least 50 footcandles of general lighting. Use a protected lamp suitable for open luminaires and do not use a lensed or enclosed lamp. Slightly higher light levels may be provided for the main basketball court in middle schools and high schools. Consider adding a wire cage to open luminaires that may be exposed to flying balls or other damage.
2. **Compact Fluorescents**. Employ industrial-style luminaires having multiple compact fluorescent lamps in a single housing. Each luminaire should use (8) 32 or 42-watt compact fluorescent triple-tube lamps, with electronic ballasts. The fixture should not have a lens, but consider adding a wire cage to open luminaires that may be exposed to flying balls or other damage.
3. **T-5HO Strip Fluorescent**. Employ industrial fluorescent luminaires with T-5HO or T-8 lamps. Each luminaire should have symmetric reflectors for downlight distribution and a wire cage or lens should be used to protect the lamps from flying balls. Four foot luminaires with 4 or 6 lamps and 2-lamp ballasts produce similar results as a like number of metal halide luminaires, but with fewer watts and greater versatility..

It will also be necessary to provide an emergency lighting system. In addition to self-illuminated exit signs, provide either:

- With the metal halide scheme, use quartz auxiliary lamps in some of the luminaires that are powered from an emergency generator or battery backup power source.
- With the compact fluorescent or strip fluorescent schemes, provide separate normal and emergency circuits, connecting certain luminaires to a source of emergency power; or
- With all schemes, provide a separate halogen downlight system that is powered in full or in part from an emergency generator or battery backup power source.

If a separate downlighting system is used, use suspended cylinder downlights using halogen IR PAR-38 flood lamps. Design the system to provide at least 5 footcandles of illumination with normal power and one footcandle from an emergency source. This system provides both egress lighting and serves other uses (see below).

*T-5HO Systems are very energy efficient and flexible. Photo Courtesy James K. Rogers*

## Description

The height of the ceiling of a gym space plays a major role in choosing gym lighting systems. This can be partly assessed by examining the coefficient of utilization (CU) at RCR=2.5 of candidate systems. It is also useful to examine their S/MH (spacing criterion) as well.

Fluorescent systems using multiple T-5HO or T-8 lamps are preferred for ordinary gyms and other high ceiling spaces. Superior color, elimination of flicker and the ability to turn lights on and off as needed are major advantages over HID systems. The added cost of the fluorescent system is offset by much lower energy use, estimated to be as much as 50% less if the multiple light level capability of a fluorescent system is utilized. Systems using multiple compact fluorescent lamps also provide these benefits, although without the high efficacy of the linear fluorescent lamps.

In general, metal halide high bay lighting systems tend to be more appropriate when ceilings are especially tall, such as a field house. Long lamp life and a minimum number of luminaires keep costs down. The color of metal halide is suitable for television as well as everyday use. The long warm up and restrike periods of metal halide lighting are a drawback since switching lights off regularly is not recommended.

A separate downlight system using halogen lamps is highly recommended for two reasons:

1. It is an instant on-instant off system that can be dimmed inexpensively. This feature is especially important if metal halide lights are accidentally extinguished, as they will require a 5-10 minute cool off and restrike delay.
2. A dimmable tungsten downlighting system can make the gym more appealing for social events, and can also serve as a "house" lighting system for many of the gym's performance and entertainment uses.

## Applicability

This Guideline can be used in most schools, including colleges and universities, public K-12, private and parochial schools, and similar facilities such as churches, sports clubs and private institutions.

## Applicable Codes

### Electrical

The electrical portion of lighting installations is usually governed by the National Electric Code (NEC). Some cities have unique electrical codes, but most adopt the NEC. The energy considerations of lighting fall under California Title 24 (or similar codes in other states). Title 24 limits the amount of lighting power in a gym to 1.6 w/sf (1999), so this recommendation exceeds code limits by a considerable amount. Title 24 also requires switching (see below under "design details").

### Life Safety

As a place of assembly, the gym needs to be equipped with an emergency lighting system capable of producing at least 1.0 footcandles, average, along the path of egress. The emergency lighting system must be powered from an emergency generator or from a battery backup system capable of providing egress lighting for at least 90 minutes. In addition, exit signs must be provided and they, too, must be powered for at least 90 minutes after a power outage.

### Seismic

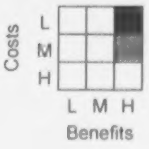
Luminaires need to be restrained in case of an earthquake. In general, this means that each luminaire must be secured to the structure with an additional safety cable independent of the fixture's ordinary support system.

## Integrated Design Implications

High bay luminaires are easily attached to most structures. It is recommended that the luminaires be suspended within the "truss space", or in other words, with the bottom of the luminaire not lower than the lowest beam or truss member. In the rare instance where the gym has a finished ceiling, recessed lighting should be considered.

## Costs[11]

Each metal halide luminaire costs about $325, or about 79 mean lumens per dollar. A multiple compact fluorescent luminaire costs about $425 or about 52 mean lumens per dollar. A T-5HO 6-lamp luminaire costs about $400, or about 71 mean lumens/dollar. Each PAR38 downlight costs about $150. Dimming, switching and emergency power costs vary and are in addition to the luminaire costs.



## Benefits

The best solution for a particular gym depends on use hours and other variables.

- A metal halide lighting system is the least first cost. There is no less expensive way to provide the necessary quantity of light from this mounting height. The use of high wattage metal halide lamps minimizes the number of luminaires (first costs) and the number of lamps (maintenance costs).
- A system employing multiple T-5HO or T-8 lamps offers the least energy use and longest life lamps (maintenance costs). Multiple light level capability saves additional energy and extends maintenance periods.
- A system using multiple compact fluorescent lamps combines the flexibility of fluorescent systems with the appearance of HID. While most costly, this approach results in a flexible design that can be energy effective if multiple light levels are used, and the system looks like a metal halide system.

## Design Tools

A modern lighting program using radiosity or ray tracing methods to calculate illumination at specific points should be used. However, minimally acceptable results may be obtained using lumen method or watts-per-square-foot methods

## Design Details

- The T-5HO system is a relatively new solution. It requires specific considerations for reflector shape, photometry, and lamp protection. Presently, only companies specializing in retrofit and similar energy efficiency products catalog luminaires. Careful study to ensure proper lighting levels is recommended.
- Metal halide "high bay" luminaires are commonly available in a number of reflector types including aluminum, ribbed acrylic and ribbed glass. Among these, ribbed acrylic probably offers the best combination of efficiency and uplight, and is sufficiently durable for the application.
- It is critical to specify the 320 to 450-watt, pulse start, 277-volt reactor ballast system. If 277 volts is not available, then use a 120-volt CWA ballast, although it is less energy efficient. Do not use the

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[11] Approximate cost to Owner, including labor, materials, overhead, profit, and costs of construction for lighting including luminaires, lamps, and suspension hardware. Includes connecting luminaire to branch circuit. Controls and branch circuit costs not included. Based on July, 2000 prices. Costs can vary depending on market conditions.

standard ("probe start") 400-watt metal halide system, as it produces less maintained light than the 320 pulse start.

- In gyms with skylights (highly recommended), the use of a two-level controller for the metal halide lamps should be considered. A photoelectric switch, sensing when adequate daylight is present to turn lights down to the "low" setting, should control the action.
- Switching of metal halide lamps should NOT be readily accessible. It should be in a controlled location such as electric room, press box, teacher/coach's office, or other location where inadvertent operation of the lights will not occur. This adds support to the concept of a separate halogen system in which the switch is quite accessible. It would be a good idea to interlock the two systems such that the halogen system can not operate once the metal halides are at or near full light.

### Operations and Maintenance

This design should be easy to operate and manage. Dimming on the halogen system (if used) will extend lamp life, and a metal halide system will require relamping every 12,000-14,000 hours (depending on hours of operation, this could be 3-5 years). System cleaning should be simple. Linear Fluorescent systems require relamping every 15,000-20,000 hours, but compact fluorescent systems require relamping every 8,000-10,000 hours. However, if both fluorescent lamp systems rotate lamp operation at reduced light levels, relamping cycles can be very long.

The control system should be designed for easy use. Automatic time of day control with manual override is an acceptable means to control the metal halide lamps, but make certain that the controller is easily programmed for days on and off, holiday schedules, etc.

### Commissioning

These systems are relatively easy to commission. Perhaps the most critical step is ensuring that automatic lighting controls, such as a photoelectric controller for a high-low system or an automatic time of day controller, are properly set up.

### Example (model)

Windsor High School, Windsor CA
Windsor Unified School District,
Quattrocchi / Kwok Architects

### References and additional information

Additional information about the basic lighting technologies can be found in the Advanced Lighting Guidelines and the IESNA Lighting Handbook.

# Guideline EL6: Corridor Lighting

## Recommendation

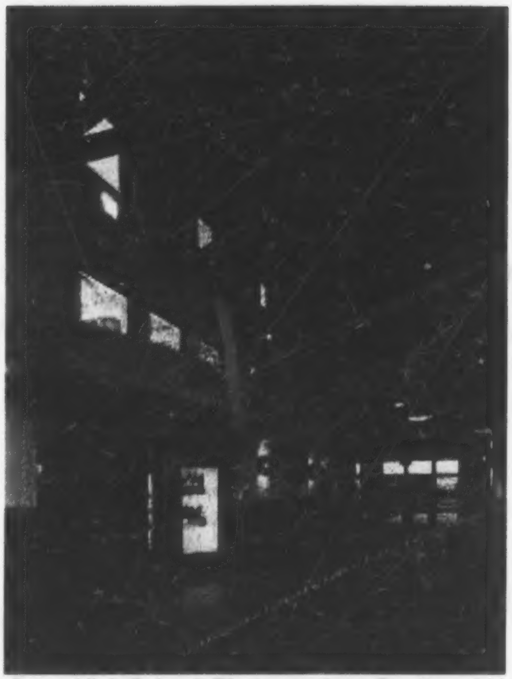
There are two principal choices for illuminating corridors in schools:

- Employ recessed fluorescent luminaires that have a means to both protect the lamp and create relatively high angle light perpendicular to the corridor axis; or
- Employ surface mounted corridor "wrap around" fluorescent luminaires designed for rough service applications.

In either case, luminaires should use T-5 or T-8 lamps and electronic ballasts. Caution should be employed to ensure that the luminaires are not overly "institutional" in appearance. Align luminaires parallel to corridor walls to provide good quality of light and to make light useful for lockers.

Outdoor corridors and corridors with plentiful daylight should employ automatic daylight switching or dimming to reduce electric lighting by day.

It will be necessary to provide emergency lighting with this lighting system. Some of these luminaires must be powered from an emergency generator or battery backup power source.



*Anzar High School, Photo courtesy Quattrocchi / Kwok Architects*

| Applicable Spaces | | Climates | | When to Consider | |
|---|---|---|---|---|---|
| Classrooms | ☐ | South Coast | ■ | Programming | ■ |
| Library | ☐ | North Coast | ■ | Schematic | ■ |
| Mulit-Purpose / Cafeteria | ☐ | Central | ■ | Design Dev | ■ |
| Gym | ☐ | Mountains | ■ | Contract Docs | ■ |
| Corridors | ■ | Desert | ■ | Construction | ■ |
| Administration | ☐ | | | Commissioning | ☐ |
| Toilets | ☐ | | | Operation | ☐ |
| Other | ☐ | | | | |

## Description

It is important to minimize downlighting so that the walls of the corridor will be better illuminated. Lights that emit very well to the sides should be chosen. Choose from among the following types or similar products:

- Interior corridors may employ "recessed indirect" luminaires. Luminaires should be oriented with the lamp long axis along the corridor long axis. This design is suited for all ceiling types.
- As an alternative, especially for schools where vandalism is a concern, use surface ceiling wraparound luminaires, preferably vandal resistant or high abuse types.
- Exterior corridors should employ surface-mounted wraparounds or ceiling-mounted, high abuse luminaires. In some cases, wall-mounted, high abuse luminaires may be acceptable.

## Applicability

This Guideline can be used in most schools, including colleges and universities, public K-12, private and parochial schools, and similar facilities such as churches, sports clubs and private institutions.

## Applicable codes

### Electrical

The National Electric Code (NEC) usually governs the electrical portion of lighting installations. Some cities have unique electrical codes, but most adopt the NEC. The energy considerations of lighting fall under California Title 24 (or similar codes in other states). Title 24 limits the amount of lighting power in a corridor to 0.6 w/sf (1999), so this recommendation exceeds code limits. Title 24 also requires switching (see below under "design details").

### Life Safety

As a path of egress, the corridor needs to be equipped with an emergency lighting system capable of producing at least 1.0 footcandles, average, along the path of egress. In general, the best way to do this is to power every third or fourth luminaire from an emergency source, which must be either an emergency generator or a battery backup system capable of providing egress lighting for at least 90 minutes. In addition, exit signs must be provided and they, too, must be powered for at least 90 minutes after a power outage.

### Seismic

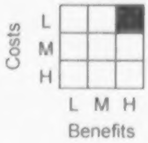
Luminaires need to be restrained in case of an earthquake. In general, this means that each luminaire must be secured to the structure with an additional hanger wire or support independent of the ceiling's support system.

## Integrated Design Implications

Given the choices of luminaires that are available, it should be possible to find an attractive solution that is suitable for any type of corridor ceiling construction, including indoor and outdoor corridors, acoustical tile or wallboard ceilings, etc.

## Costs

Each corridor luminaire costs about $200[12]. Dimming, switching and emergency power costs vary and are in addition to the luminaire costs.



## Benefits

Fluorescent corridor lighting systems provide solid results for a modest investment. By carefully choosing a rough service grade luminaire, long product life will result.

## Cost Effectiveness

The corridor lighting systems recommended here are very cost effective.

## Design Tools

A modern lighting program using radiosity or ray tracing methods to calculate illumination at specific points should be used. However, minimally acceptable results may be obtained using lumen method or watts-per-square-foot methods

## Design Details

The following are typical lighting layouts for corridors.

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[12] *Approximate cost to Owner, including labor, materials, overhead, profit, and costs of construction for lighting including luminaires, lamps, and suspension hardware. Includes connecting luminaire to branch circuit. Controls and branch circuit costs not included. Based on July 2000 prices. Costs can vary depending on market conditions.*

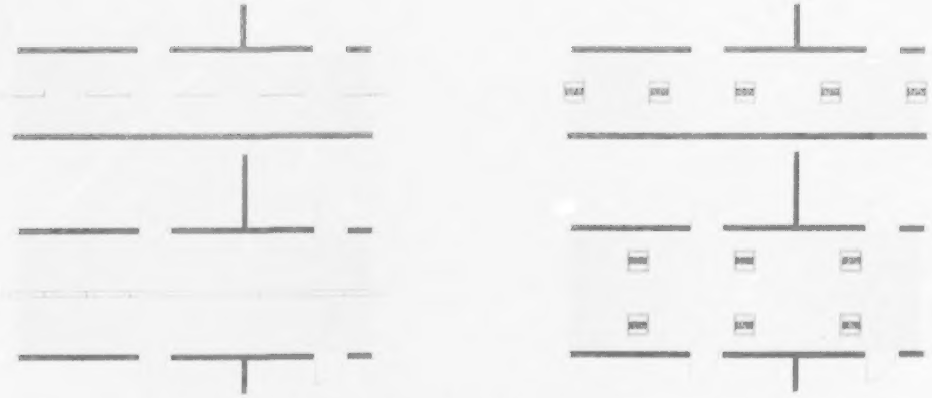


Figure 7 – Corridor Lighting Designs

- If required by the application, choose one of many modern "rough service" luminaires that are attractive as well as durable.
- In general, recessed downlights generally have insufficient vertical illumination to provide good service in corridors. However, recessed downlights using compact fluorescent lamps may be preferred for lobbies and similar applications where a dressier appearance is desired.
- Switching of the lighting system should NOT be readily accessible. IN general, switching should utilize an automatic time of day control system with motion sensor override during normally "off" hours.
- In addition, provide automatic daylighting controls, including dimming or switching of corridor lights in corridors having windows, skylights or other forms of natural lighting.

### Operations and Maintenance

This design should be easy to operate and manage. As with most fluorescent lighting systems, relamping every 12,000-14,000 hours is recommended. Ballast life should be 10 years or more. System cleaning should be simple.

The control system should be designed for easy management. Automatic time of day control with override is an acceptable means to control corridor lights, but make certain that the controller is easily programmed for days on and off, holiday schedules, etc.

### Commissioning

These systems are relatively easy to commission. Perhaps the most critical step is ensuring that automatic lighting controls, such as a photoelectric controller for a high-low system or an automatic time of day controller, are properly set up.

### Example(s)

### References and additional information

Additional information about the basic lighting technologies can be found in the *Advanced Lighting Guidelines* and the IESNA *Lighting Handbook*. Also, see *IESNA RP-3-00: Lighting for Educational Facilities*.

# Guideline EL7: Lighting for A Multi-Purpose Room

## Recommendation

As a minimum, a multi purpose room should have at least two independent lighting systems:

- A general lighting system providing 20-30 footcandles of uniform illumination using standard T-8 lamps; and
- A dimmable "house lighting" system supporting audio visual and social uses of the room, producing no more than 5 footcandles.

*Photo courtesy: SunOptics Prismatic Skylights*

The general lighting system should probably be one of the types previously suggested for classroom lighting. If suspended luminaires are chosen, be careful to locate luminaries so as not to interfere with audio-visual and other uses of the room. If the room's program includes any sports or games, all lighting systems should be recessed or otherwise protected from damage.

The house lighting system should probably employ recessed or surface downlights. Narrow beam downlights should be chosen, and halogen lighting is recommended for reasons of superior color, inexpensive dimming, and good light control. The house lighting system should be laid-out to prevent light from striking walls or screens. Note that some general lighting systems might also serve as the house lighting system if properly laid out and equipped with electronic dimming ballasts, but most general lighting systems generate too much diffuse light, even when dimmed, for A/V use.

| Applicable Spaces | | Climates | | When to Consider | |
|---|---|---|---|---|---|
| Classrooms | ☐ | South Coast | ■ | Programming | ■ |
| Library | ☐ | North Coast | ■ | Schematic | ■ |
| Mulit-Purpose / Cafeteria | ■ | Central | ■ | Design Dev | ■ |
| Gym | ☐ | Mountains | ■ | Contract Docs | ■ |
| Corridors | ☐ | Desert | ■ | Construction | ■ |
| Administration | ☐ | | | Commissioning | ☐ |
| Toilets | ☐ | | | Operation | ☐ |
| Other | ☐ | | | | |

As with corridors and other common spaces, a control system that activates the general lighting system according to a calendar program and employs motion sensing for "off" hours should be used. Rooms with plentiful daylight should employ automatic daylight switching or dimming to reduce electric lighting by day. A manual override switch should be provided. Manual dimming of the house lighting system should be provided along with an interlock switch preventing simultaneous operation of both general and house lighting.

It will be necessary to provide emergency lighting with this lighting system. Some of these luminaires must be is powered from an emergency generator or battery backup power source.

## Description

For possible general lighting systems, see Lighting Guidelines 1-3.

For downlights, halogen lamps are recommended for reasons of cost, beam control, and ease of dimming. Luminaires should use standard IR halogen PAR lamps. Black baffles or black alzak cone trims are recommended for A/V applications.

## Applicability

This Guideline can be used in most schools, including colleges and universities, public K-12, private and parochial schools, and similar facilities such as churches, sports clubs and private institutions.

## Applicable codes

### Electrical

The National Electrical Code usually governs the electrical portion of lighting installations. Some cities have unique electrical codes, but most adopt the NEC. The energy considerations of lighting fall under California Title 24 (or similar codes in other states). Title 24 limits the amount of lighting power in a cafeteria or multi-purpose room to 1.6 w/sf (1999), so this recommendation is within code limits. Title 24 also requires switching. Keep in mind that if the two lighting systems are interlocked as described above, only the higher wattage system is counted in energy code calculations.

### Life Safety

As a place of assembly, the room needs to be equipped with an emergency lighting system capable of producing at least 1.0 footcandles, average, along the path of egress. In general, the best way to do this is to power some of the lighting from an emergency source, which must be either an emergency generator or a battery backup system capable of providing egress lighting for at least 90 minutes. In addition, exit signs must be provided and they, too, must be powered for at least 90 minutes after a power outage.

The controls must be designed such that, regardless of setting, if a power emergency occurs, the proper lights are illuminated. This often requires use of automatic transfer relay or other mechanism that bypasses room controls during a power emergency. Transfer relays must be listed for use in emergency circuits.

### Seismic

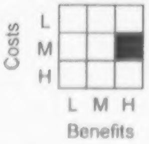
Luminaires need to be restrained in case of an earthquake. In general, this means that each luminaire must be secured to the structure with an additional hanger wire or support independent of the ceiling's support system.

## Integrated Design Implications

Because multi-purpose rooms often serve as cafeteria, study hall, social gathering spot, special event space, and community meeting and A/V facility, it is extremely important to ensure that the lighting and controls provide proper operation for every intended use of the room. Moreover, this room may benefit from greater architectural design than other spaces, and lighting designers should be prepared to creatively provide the functions of the lighting described here, but using other types of equipment better suited to the specific architecture.

## Costs[13]

Each downlight costs about $175 (for general lighting costs, see other Guidelines). Dimming, switching and emergency power costs vary and are in addition to the luminaire costs.



## Benefits

This "two component" lighting design approach, when combined with effective controls, permits a wide range of uses of the multi-purpose room, exactly what is was designed for.

## Cost Effectiveness

In general, two separate lighting systems, with one being a dimmed halogen system, is the most cost effective. A single fluorescent lighting system with dimming system is usually more costly and less flexible.

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[13] *Approximate cost to Owner, including labor, materials, overhead, profit, and costs of construction for lighting including luminaires, lamps, and suspension hardware. Includes connecting luminaire to branch circuit. Controls and branch circuit costs not included. Based on July 2000 prices. Costs can vary depending on market conditions.*

### Design Tools

A modern lighting program using radiosity or ray tracing methods to calculate illumination at specific points should be used. However, minimally acceptable results may be obtained using lumen method or watts-per-square-foot methods

### Design Details

The following shows a typical multi-purpose room with two lighting schemes. The left side uses pendant mounted luminaires and the right side shows recessed troffers.

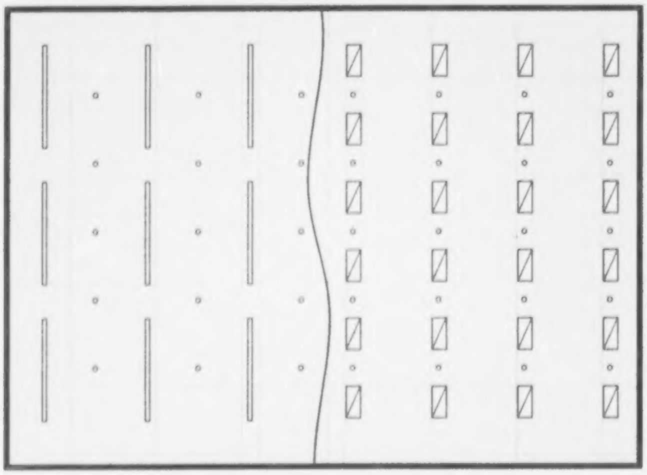


*Figure 8 – Multi-Purpose Lighting Designs*

*This illustrates two approaches to lighting multi-purpose rooms. Suspended direct/indirect lighting is used on the left side and standard lensed troffers are used on the right side. Both schemes have a separate system of downlights to serve as "house" lights for social and A/V use.*

- In this room, self-contained emergency ballast/battery units should be avoided unless they are of a special design employing an external voltage sense connection. Leaving any general lighting luminaire operating in the dimmed mode is usually not acceptable.
- Consider laying out the lighting in zones that have individual manual override switches. This will permit de-activating a zone when not occupied.
- Switching and dimming of the lighting system should NOT be readily accessible. Locate controls in a supervised location.
- Consider a modern preset dimming or control system, especially if touch screen control and other modern A/V interfaces are planned.

### Operations and Maintenance

This design should be easy to operate and manage. As with most fluorescent lighting systems, the general lighting system should be relamped every 12,000-14,000 hours. Ballast life should be 10 years or more. Spot relamping is recommended for the house lighting system. Cleaning of both systems should be simple.

The control system should be designed for easy management. Automatic time of day control with override is an acceptable means to control corridor lights, but make certain that the controller is easily programmed for days on and off, holiday schedules, etc.

### Commissioning

These systems are relatively easy to commission. Perhaps the most critical step is ensuring that automatic lighting controls, such as a photoelectric controller for a high-low system or an automatic time of day controller, are properly set up. Also, if fluorescent dimming is used, make sure that lamps are operated at full light for 100 hours prior to dimming them.

### Example(s)

### References and additional information

Additional information about the basic lighting technologies can be found in the *Advanced Lighting Guidelines* and the *IESNA Lighting Handbook*. Also, see *IESNA RP-3-00: Lighting for Educational Facilities*.

# Guideline EL8: Lighting for A Library or Media Center

**Recommendation**

Provide lighting for a library as follows:

- A lighting system providing 20-30 footcandles of general illumination in casual reading, circulation and seating areas using standard T-8 lamps
- Overhead task lighting at locations such as conventional card files, circulation desks, etc.
- Task lighting at carrels and other obvious task locations, using compact fluorescent or T-8 lamps
- Stack lights using T-8 or T-5 lamps in areas where stack locations are fixed, and general overhead lighting in areas employing high density stack systems
- Special lighting for media rooms as required

Austin Creek *Elementary School,*
*Photo courtesy: Quattrocchi / Kwok Architects*

| Applicable Spaces | | Climates | | When to Consider | |
|---|---|---|---|---|---|
| Classrooms | ☐ | South Coast | ■ | Programming | ■ |
| Library | ■ | North Coast | ■ | Schematic | ■ |
| Mulit-Purpose / Cafeteria | ☐ | Central | ■ | Design Dev | ■ |
| Gym | ☐ | Mountains | ■ | Contract Docs | ■ |
| Corridors | ☐ | Desert | ■ | Construction | ■ |
| Administration | ☐ | | | Commissioning | ■ |
| Toilets | ☐ | | | Operation | ☐ |
| Other | ☐ | | | | |

The general lighting system may be one of the types previously suggested for classroom lighting. As long as adequate ceiling height is present, suspended lighting systems are preferable. Overhead lighting systems for task locations should also be selected from among choices suitable for classrooms or offices.

Task lighting at carrels and other spots should be selected according to architecture and finish details. Two common options include

- Under shelf task lights using T-8 or modern T-5 lamps (e.g. F14T5/8xx, F21T5/8xx, or F28T5/8xx)
- Table or floor lamp equipped with a compact fluorescent lamp up to 40 watts

Stack lighting should utilize luminaires specifically designed for lighting stacks. There are a number of choices, but generally, a single continuous T-8 or T-5 lamp system will provide adequate illumination.

Media rooms, such as video monitoring and editing, sound monitoring and editing, distance learning and video teleconferencing all have special requirements. It is important that lighting be designed to meet the specific requirements and that lighting controls be provided to enable room use. No specific recommendations are made here, but depending on the room, professional lighting design services may be needed to assist the standard A/E design team.

A control system that activates the general lighting system according to a calendar program and employs motion sensing for "off" hours should be used. In areas with plentiful daylight, employ automatic daylight switching or dimming to reduce electric lighting by day. In addition, in areas of the library that are less often used, such as reference stacks, consider providing individual motion sensors or digital time switches for stack aisles that are connected to dimming ballasts, producing low light levels (but not off) until the aisle is occupied. Individual reading and study rooms should employ motion sensors, and "personal" motion sensors and plug strips should be used at study carrels, especially those with fixed computers.

It will be necessary to provide emergency lighting with this lighting system. Some of the general lighting luminaires must be is powered from an emergency generator or battery backup power source.

## Description

For possible general lighting systems, see Lighting Guidelines 1-3 and 9. For office lighting systems, see Lighting Guideline 9.

## Applicability

This Guideline can be used in most schools, including colleges and universities, public K-12, private and parochial schools, and similar facilities containing libraries, such as churches and private institutions.

## Applicable codes

### Electrical

The National Electrical Code usually governs the electrical portion of lighting installations. Some cities have unique electrical codes, but most adopt the NEC. The energy considerations of lighting fall under California Title 24 (or similar codes in other states). Title 24 limits the amount of lighting power in a library reading area to 1.2 w/sf and a stack area to 1.5 w/sf (1999), so this recommendation is within code limits. Title 24 also requires switching.

### Life Safety

As a place of assembly, libraries must be equipped with an emergency lighting system capable of producing at least 1.0 footcandles, average, along the path of egress. In general, the best way to do this is to power some of the lighting from an emergency source, which must be either an emergency generator or a battery backup system capable of providing egress lighting for at least 90 minutes. In addition, exit signs must be provided and they, too, must be powered for at least 90 minutes after a power outage.

### Seismic

Luminaires need to be restrained in case of an earthquake. In general, this means that each luminaire must be secured to the structure with an additional hanger wire or support independent of the ceiling's support system.

## Integrated Design Implications

Libraries are often more highly designed than other spaces. In some designs, other lighting systems will integrate better with the architecture and should be considered.

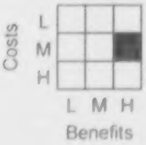
## Costs[14]

| | |
|---|---|
| 4' long stack light | $200 |
| 3' long undercabinet task light | $175 |
| High quality compact fluorescent desk lamp | $300 |

Dimming, switching and emergency power costs vary and are in addition to the luminaire costs.

## Benefits

These recommendations provide proper light for a library and media center. Task light levels are provided only at task locations, while ambient and general light levels are lower to ensure energy efficient operation.



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[14] Ibid.

### Cost Effectiveness

Library spaces will tend to be among the most expensive to light. These recommendations provide a good balance between cost, energy efficiency, and good lighting practice.

### Design Tools

A modern lighting program using radiosity or ray tracing methods to calculate illumination at specific points should be used. However, minimally acceptable results may be obtained using lumen method or watts-per-square-foot methods

### Design Details

The following is a lighting design for a typical library.

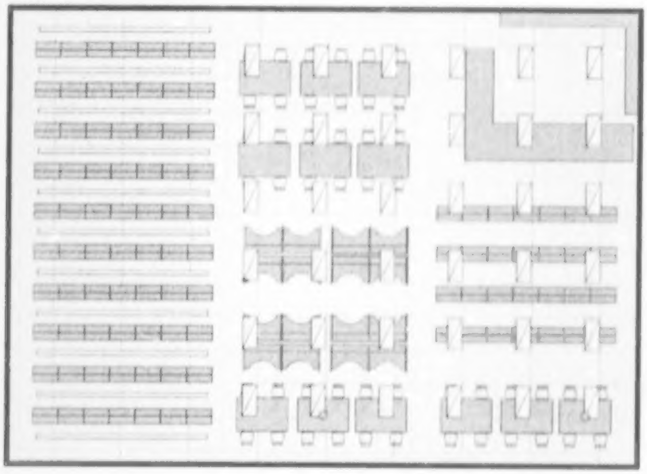


*Figure 9 – Library Lighting Design*

*This design illustrates general lighting using troffers, table lights for study desks, task lights at kiosks, and stack lights. Using high ballast factor 2-lamp troffers, this design works at an overall power density of 1.27 W/sf. Increasing stack lights to high ballast factor increases overall connected power to 1.38 W/sf. Note that the stacks to the right on the plan are half height.*

- The general lighting system can be designed to become more "dense" in task areas such as circulation desks, thus minimizing the number of different lighting types.
- Undercabinet task lights should be specified carefully. Avoid traditional "inch light" systems with magnetic ballasts that use twin tube compact fluorescent lamps and old-style linear lamps like the F6T5 (9"), F8T5 (12"), and F13T5 (21"). Use tasks lights employing modern F14T5 (22"), F21T5 (34"), or F28T5 (46"), or F17T8, F25T8 or F32T8 lamps. Always use electronic ballasts, and consider dimming for all task lights.
- Desk lamps and table lamps with compact fluorescent hardwired lamps should be used. There are relatively few products. Medium based screw-in compact fluorescent lamps are not a good choice for new products.
- Switching and dimming of the lighting system should NOT be readily accessible. Locate controls in a supervised location.
- In media rooms, consider a modern preset dimming or control system, especially if touch screen control and other modern A/V interfaces are planned.

## Operations and Maintenance

This design should be easy to operate and manage. As with most fluorescent lighting systems, the general lighting system should be relamped every 12,000-14,000 hours. Ballast life should be 10 years or more Spot relamping is recommended for the house lighting system. Cleaning of both systems should be simple.

## Commissioning

These systems are relatively easy to commission. Perhaps the most critical step is ensuring that automatic lighting controls, such as a photoelectric controller for a high-low system or an automatic time of day controller, are properly set up. Also, if fluorescent dimming is used, make sure that lamps are operated at full light for 100 hours prior to dimming them.

## Example

## References and additional information

Additional information about the basic lighting technologies can be found in the *Advanced Lighting Guidelines* and the *IESNA Lighting Handbook*. Also, see *IESNA RP-3-00: Lighting for Educational Facilities*.

# Guideline EL9: Lighting for Offices and Teacher Support Rooms

## Recommendation

This recommendation is for offices and teacher support rooms having a ceiling no more than 12' high and a flat suspended acoustical tile ceiling. There are two choices:

1. Use recessed fluorescent lens troffers having at least 78% luminaire efficiency, using T-8 premium lamps and electronic ballasts and a connected lighting power of 0.9 to 1.1 watts per square foot
2. Use suspended indirect lighting to produce an ambient level of 15-20 footcandles (about 0.6 w/sf) and task lighting where required.

## Description

See Lighting Guidelines 1 and 2.

## Applicability

### Applicable codes

The National Electric Code (NEC) usually governs the electrical portion of lighting installations. Some cities have unique electrical codes, but most adopt the NEC. The energy considerations of lighting fall under California Title 24 (or similar codes in other states). Title 24 limits the amount of lighting power in offices to 1.3 w/sf (1999), so this recommendation meets code limits by a considerable amount. Title 24 also requires switching (see Guideline 4).

Luminaires need to be restrained in case of an earthquake. In general, this means that each luminaire must be hung from the structure with hanger wires independent of the ceiling system.

*Naomi Miller, photographer.*

**Applicable Spaces**
- Classrooms
- Library
- Multi-Purpose / Cafeteria
- Gym
- Corridors
- Administration ■
- Toilets
- Other

**Climates**
- South Coast ■
- North Coast ■
- Central ■
- Mountains ■
- Desert ■

**When to Consider**
- Programming ■
- Schematic ■
- Design Dev ■
- Contract Docs ■
- Construction ■
- Commissioning
- Operation

## Integrated Design Implications

This type of lighting should only be used in flat acoustic tile ceilings, and then only when ceiling height and/or budget prevents consideration of other options.

## Costs

See Guidelines 1 and 2.

| Costs | L | M | H |
|---|---|---|---|
| L | | ■ | |
| M | | | ▨ |
| H | | | |
| | Benefits | | |

## Benefits

Troffer lighting systems generally offer excellent efficiency, but with some loss of visual comfort. They make excellent use of the low-cost, widely used T-8 lamp system. Systems operating at about 1.0 w/sf will generate between 50 and 60 foot-candles maintained average, with very good uniformity. Separate task and ambient systems may create a more comfortable atmosphere.

### Cost Effectiveness

Lens troffer lighting systems are low in cost, but their inexpensive appearance can be a drawback. Suspended lighting systems provide a high degree of cost effectiveness and improved appearance in most applications.

### Design Tools

A modern lighting point calculation program using radiosity or ray tracing methods should be used. However, minimally acceptable results will be obtained using lumen method or watts-per-square-foot methods.

### Design Details

See Lighting Guidelines 1 and 2.

For non-dimming applications, luminaire light and power can be varied through choice of ballast factor. Use Table 11 and specify ballasts accordingly.

### Operations and Maintenance

These lighting systems rarely need maintenance. As with all fluorescent systems, lamps should be replaced at approximately 12,000-16,000 hours of operation, which with normal school use could be as seldom as every 6 years. Luminaires should be cleaned annually. Lensed luminaires require periodic cleaning and are occasionally abused. Lens replacement is relatively cheap and an acceptable condition even in applications where the designer expects poor maintenance and abuse.

### Commissioning

None other than preconditioning of lamps in dimming applications.

### Example (model)

### References and additional information

Readers may wish to consult the *Advanced Lighting Guidelines* and the IESNA *Lighting Handbook*. Also, see *IESNA RP-3-00: Lighting for Educational Facilities*.

# Guideline EL10: Lighting for Locker and Toilet Rooms

## Recommendation

This recommendation is for locker and toilet rooms:

- Over mirrors and vanities, employ rough service grade fluorescent wall-mounted lights.
- Over stalls and locker areas, employ recessed or surface-mounted rough service area fluorescent lights.
- In showers, employ ceiling-mounted, watertight, rough-service grade fluorescent lights.

In general, choose luminaires that are attractively styled to prevent an overly institutional appearance.

| Applicable Spaces | |
|---|---|
| Classrooms | ☐ |
| Library | ☐ |
| Mulit-Purpose / Cafeteria | ☐ |
| Gym | ▨ |
| Corridors | ☐ |
| Administration | ☐ |
| Toilets | ■ |
| Other | ☐ |

| Climates | |
|---|---|
| South Coast | ■ |
| North Coast | ■ |
| Central | ■ |
| Mountains | ■ |
| Desert | ■ |

| When to Consider | |
|---|---|
| Programming | ■ |
| Schematic | ■ |
| Design Dev | ■ |
| Contract Docs | ■ |
| Construction | ☐ |
| Commissioning | ☐ |
| Operation | ☐ |

## Description

This guideline generally recommends fluorescent luminaires using standard T-8 or compact fluorescent lamps. These luminaires are part of a relatively new generation of "vandal resistant" or "rough service" lights that are considerably more attractive than previous products. These luminaires should be specified with UV-stabilized, prismatic polycarbonate lenses for maximum efficiency and resistance to abuse. The use of tamper resistant hardware is also recommended.

Wall mounted rough-service lights include

- Linear lights using T-8 lamps and electronic ballasts
- Rectangular, oval and round lights that can be equipped with compact fluorescent lamps (low wattage HID lamps can also be used in these luminaires but are not recommended)

Recessed ceiling lights are generally troffers (see Guideline 2) that employ the polycarbonate lens and tamper resistant hardware, as well as more robust components. These luminaires are available in 1x4, 2x2, and 2x4 versions with standard T-8 lamps and electronic ballasts.

For showers, employ either surface or recessed luminaires designed for compact fluorescent lights. Due to the long warm up and restrike times, HID lamps should not be used. In either case, luminaires should be listed for wet applications.

## Applicability

## Applicable codes

### Electrical

The National Electrical Code (NEC) usually governs the installation of lighting installations. Some cities have unique electrical codes, but most adopt the NEC. The energy considerations of lighting fall under California Title 24 (or similar codes in other states). Title 24 limits lighting power to 0.9 w/sf in a locker or dressing room to 0.9 w/sf, and to 0.6 w/sf in rest rooms (1999). Title 24 also requires switching in these spaces (see Guideline 4).

**Life Safety**

The room needs to be equipped with an emergency lighting system capable of producing at least 1.0 footcandles, average, along the path of egress. In general, the best way to do this is to power some of the lighting from an emergency source, which must be either an emergency generator or a battery backup system capable of providing egress lighting for at least 90 minutes. In addition, exit signs must be provided and they, too, must be powered for at least 90 minutes after a power outage.

**Seismic**

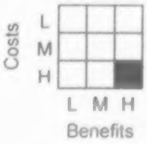
Luminaires need to be restrained in case of an earthquake. In general, this means that each suspended luminaire must be hung from the structure with hanger wires independent of the ceiling system.

### Integrated Design Implications

These types of spaces are historically the most abused interior portions of school buildings. Durable lighting is unfortunately less attractive and less "integrated" than other lighting types.

### Costs[15]

Rough service lighting systems will cost about $200-$300 per luminaire for the types listed above with compact fluorescent or T-8 lamps and an electronic ballast.



### Benefits

Rough service lighting will last longer in these applications while continuing to look good and not suffer from cracks and other signs of abuse.

### Cost Effectiveness

The investment in rough service equipment is paid back over time. In high schools and colleges, the payback can be rapid, especially if the students are particularly rough or abusive.

### Design Tools

A modern lighting point calculation program using radiosity or ray tracing methods should be used. However, minimally acceptable results will be obtained using lumen method or watts-per-square-foot methods.

### Design Details

Be certain to employ premium T-8 lamps with 835 or 841 color, rated at 24,000 hours. For non-dimming applications, luminaire light and power can be varied through choice of ballast factor. Use Table 11 and specify ballasts accordingly.

Controls should perform in one of the following ways:

- Continuously on during normal school hours, with a night/emergency light on all the time; or
- Continuously on during normal school hours, with both a night/emergency light on at all times and a motion sensor override for full lighting during "off" hours.

### Operations and Maintenance

These lighting systems rarely need maintenance. As with all fluorescent systems, lamps should be replaced at approximately 12,000-16,000 hours of operation, which with normal school use could be as seldom as every 6 years. Luminaires should be cleaned annually. Lensed luminaires require periodic cleaning and are occasionally abused. Lens replacement is relatively cheap and an acceptable condition even in applications where the designer expects poor maintenance and abuse.

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[15] Ibid.

### Commissioning

None other than preconditioning of lamps in dimming applications.

### Example(s)

### References and additional information

Readers may wish to consult the *Advanced Lighting Guidelines* and the IESNA *Lighting Handbook*. Also, see *IESNA RP-3-00: Lighting for Educational Facilities*.

# Guideline EL11: Outdoor Lighting

**Recommendation**

As a minimum, provide the following exterior lighting systems:

- At every door, provide canopy or wall-mounted lights to illuminate the general area
- For parking lots, provide pole mounted lights to illuminate the lot and surrounding walks and other areas
- For driveways intended for night use, provide pole mounted lights for the drive and associated sidewalks
- For walkways intended for night use, provide suitable walkway lighting systems such as pedestrian light poles or bollards
- Other lighting as called for by the site, local requirements, etc.

Lights under canopies or mounted to walls should be attractive, rough service, semi-recessed or surface luminaires with lens. The lens should be a UV-stabilized polycarbonate prismatic lens. If mounted to walls, employ designs that direct light downward and minimize light trespass and light pollution.

| Applicable Spaces | | Climates | | When to Consider | |
|---|---|---|---|---|---|
| Classrooms | ☐ | South Coast | ■ | Programming | ■ |
| Library | ☐ | North Coast | ■ | Schematic | ■ |
| Mulit-Purpose / Cafeteria | ☐ | Central | ■ | Design Dev | ■ |
| Gym | ☐ | Mountains | ■ | Contract Docs | ■ |
| Corridors | ☐ | Desert | ■ | Construction | ■ |
| Administration | ☐ | | | Commissioning | ☐ |
| Toilets | ☐ | | | Operation | ☐ |
| Other | ■ | | | | |

Parking lots and driveways should be illuminated using pole mounted full cutoff luminaires. Luminaires should be at least 17 feet above grade; actual pole height depends on the type of pole and base. Direct burial, color impregnated composition or fiberglass poles are recommended if soil and other site conditions are acceptable; if used in the center of a large parking area, however, consider steel or aluminum poles that are anchor-bolt mounted to foundations. Typically, luminaires will employ 150 or 175-watt pulse start metal halide lamps, and in parking lots, two luminaires may be mounted to a single pole

Lower level lights may be used for walkways, especially if away from buildings and parking lots. Choose between short poles (8-12') using compact fluorescent or low wattage HID lamps, or bollards using compact fluorescent lamps.

A control system that activates the exterior lighting system according to an astronomic clock should be used, instead of a photocell. The system should permit activation at sunset and permit deactivation at a programmable time, permitting the school to be "dark" and save energy as much of the night as possible. Separate programmed "off" times for parking lot, driveway, and building lighting are highly desirable. This system should be located where accessible to administration personnel; it must be easy to set and permit manual override.

In many cases, a "dark" school after hours is highly desirable. Carefully located motion sensors can be used to activate low cost compact fluorescent or quartz lights that serve as both safety lighting and as a deterrent against vandalism.

It may be necessary to provide emergency lighting with this lighting system. Some of these luminaires must be is powered from an emergency generator or battery backup power source.

All lights should be chosen with consideration of the weather conditions under which they will operate. In most cases the primary consideration is lamp starting temperature, which is a function of both lamp and ballast. In most of California, a minimum starting temperature of –5°F is acceptable and can be obtained with certain compact fluorescent lamps as well as HID.

## Description

Pole lights should use a variation of the classic "shoebox" full cutoff lights. Avoid traditional lights or contemporary lights that do not produce full shielding. This will help prevent light trespass and light pollution.

There are many possible choices in wall lights. This is one situation where aesthetics may be critical. Be certain to choose die cast aluminum bodies, rough-service polycarbonate lenses or diffusers, and/or other heavy-duty construction. There are a number of look-alike products made of lightweight and inferior materials, so be especially wary of imitations and substitutes.

If choosing a dark school approach to security, use of motion sensors and quartz floodlights may be warranted. Either separate or integrated units may be used. Quality is especially important in choosing exterior motion sensors; a faulty sensor will give false indications and activate lights (and concerned neighbors) needlessly.

## Applicability

This Guideline can be used in most schools, including colleges and universities, public K-12, private and parochial schools, and similar facilities such as churches, sports clubs and private institutions.

## Applicable codes

### Electrical

The National Electrical Code (NEC) usually governs the electrical portion of lighting installations. Some cities have unique electrical codes, but most adopt the NEC. The energy considerations of lighting fall under California Title 24 (or similar codes in other states). Presently, there are no significant energy code limits to exterior lighting systems.

### Life Safety

Because building codes now consider the path of egress to continue outside the building, some exterior lighting may need to be equipped with emergency backup power. This is particularly true for exterior corridors. The design requirement for the backup system is at least 1.0 footcandles, average, along the path of egress. In general, the best way to do this is to power some of the lighting from an emergency source, which must be either an emergency generator or a battery backup system capable of providing egress lighting for at least 90 minutes. Exterior exit signs may also be required and they, too, must be powered for at least 90 minutes after a power outage.

Lighting controls must be designed such that, regardless of setting, if a power emergency occurs, the proper lights are illuminated. This often requires use of automatic transfer relay or other mechanism that bypasses room controls during a power emergency. Transfer relays must be listed for use in emergency circuits.

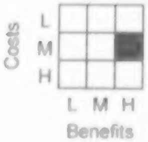
### Seismic

Building-mounted luminaires need to be restrained in case of an earthquake. In general, this means that each luminaire in a canopy must be secured to the structure with an additional hanger wire or support independent of the ceiling's support system.

## Integrated Design Implications

Exterior lights should be chosen with the architectural impact to the building exterior in mind. Select the proper color, shape, and style to reinforce architectural themes of the building itself.

## Costs[18]



- Typical pole luminaire, 17 feet high, 175 watt, type III distribution, with steel pole and anchor base, $1500
- Bollard, contemporary, with 42 watt compact fluorescent and concrete anchor base, $600
- Canopy mounted rough service luminaire, (2) 32 watt compact fluorescent, contemporary styled, $300
- High quality motion sensor floodlight, 350 watt quartz, $250

Dimming, switching and emergency power costs vary and are in addition to the luminaire costs.

## Benefits

Properly designed exterior lighting systems permit the extended use of the facility, promoting increased personal safety and security and reduced vandalism.

## Cost Effectiveness

The cost of exterior lighting tends to be relatively high. However, compromising on costs, such as using lower quality products, will result in needing to replace the lighting system sooner, thus making it a poor choice in the long run.

## Design Tools

A modern lighting program to calculate illumination at specific points should be used.

## Design Details

- Lighting layouts for parking lots and the direct pedestrian access should be performed using an outdoor lighting analysis computer program. Design criteria should be at least 0.5 footcandles in parking lots, with an average light level of 2.0 footcandles and average to minimum uniformity of 4:1 or better.
- Consider "zoning" exterior lighting so that the parking lot zone nearest the building can be activated separately from the majority of the lot.
- Manual override switching of the lighting system should NOT be readily accessible. Locate controls in a supervised location. Use a digital controller, not a mechanical "time clock".

## Operations and Maintenance

This design should be easy to operate and manage. As with most HID and compact fluorescent lighting systems, the lighting system should be group relamped every 8,000 hours, or about every 2 years. Ballast life should be 10 years or more. Spot relamping is recommended to ensure security and safety. Cleaning of systems should be simple.

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[18] Ibid.

### Commissioning

These systems are relatively easy to commission. Perhaps the most critical step is ensuring that the lighting controls are properly set up.

### Example(s)

### References and Additional Information

Additional information about the basic lighting technologies can be found in the *Advanced Lighting Guidelines* and the IESNA *Lighting Handbook*. Also, see *IESNA RP-3-00: Lighting for Educational Facilities*.

# DAYLIGHTING AND FENESTRATION DESIGN

*Gentle, diffuse daylight permeates a classroom with both sidelight and toplight. Note that all surfaces are painted white to distribute light more efficiently and reduce contrast glare. Photo courtesy Barbara Erwine*

Daylighting forms the cornerstone of sustainable, high performance design for our schools. Affecting us on both conscious and subconscious levels, it provides light to see our environment and do our work, a natural rhythm that determines the cycles of our days and seasons, and biological stimulation for hormones that regulate our body systems and moods. In addition, it offers opportunities for natural ventilation and tremendous energy savings in our electrically lit interiors. These advantages of daylighting translate to higher performance in schools. Recent research has shown that children achieve significantly higher test scores in classrooms that are daylit than in those that aren't,[17] making daylighting one of our building-related best investments for the learning environment.

This chapter provides an overview of daylighting and fenestration design. It also presents eight daylighting guidelines for specific sidelighting and toplighting schemes. In addition, the on-line Appendix that supports the Best Practices Manual provides detailed information.

Providing access to exterior views through view windows (Guideline DL1)

Introducing daylight deeper in classrooms with clerestories (Guideline DL2)

Using light shelves or louvers with clerestories to improve daylight distribution (Guideline DL3)

Balancing daylight from window walls with wall wash toplighting (Guideline DL4)

Providing even daylight in single-story classrooms with central toplighting (Guideline DL5)

Using patterned toplighting in spaces that need even illumination across a large area (Guideline DL6)

In linear spaces such as corridors, using linear toplighting to direct movement or provide visual orientation (Guideline DL7)

Employing tubular skylights for toplighting for areas with deep roof cavities and for low-cost retrofits (Guideline DL8)

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[17] Heschong Mahone Group, "Daylighting in Schools—An Investigation into the Relationship between Daylighting and Human Performance," prepared for Pacific Gas & Electric Company and funded by California utility customers, 1999.

To fully daylight most spaces, the guidelines should be combined with each other or repeated as a pattern across the space. For example, Wall Wash Toplighting (Guideline DL4) on an interior wall could be combined with High Clerestory Sidelighting (DL2) and View Windows (DL1) on an exterior wall to fully daylight a classroom. Since daylight is additive, the total amount of daylight in the space is the sum of the daylight available from each individual pattern. Each guideline represents a daylight delivery system with inherent advantages and disadvantages, which are summarized below in Table 15.

*Table 15 – Selection Criteria for Daylighting Strategies*

| *Design Criteria* | *View Windows (DL1)* | *High Sidelight w/ Light Shelf (DL2 & DL3)* | *Wall Wash Toplighting (DL4)* | *Central & Patterned Toplighting (DL5 & DL6)* | *Linear Toplighting (DL7)* | *Tubular Skylights (DL8)* |
|---|---|---|---|---|---|---|
| Uniform Light Distribution | -- | +/- | + | ++ | * | * |
| Low Glare | - | + | + | + | + | +/- |
| Reduced Energy Costs | - | + | + | ++ | + | + |
| Cost Effectiveness | + | + | + | + | + | ++ |
| Safety/Security Concerns | - | +/- | + | + | + | ++ |
| Low Maintenance | - | + | + | + | + | + |

+ Good application - Poor application * Depends on space layout and number and distribution of daylight apertures

## Overview

Daylight can be provided via windows and glazed doors, and via skylights and other forms of toplighting. These glazed openings are collectively referred to as "fenestration." The placement, design and selection of materials for fenestration is extremely important and can tip the balance between a high performance and low performance building. Fenestration impacts building energy efficiency by affecting cooling loads, heating loads and lighting loads. Visual comfort is strongly affected by the window location, shading and glazing materials. Well-designed windows can be a visual delight. But poorly designed windows can create a major source of glare. Thermal comfort can also be compromised by poor fenestration design. Poorly insulated windows add to a winter chill or summer sweat, while windows with low U-values keep glass surface temperatures closer to the interior air temperature, improving thermal comfort. And although windows and skylights provide opportunities for natural ventilation, they must be designed to ensure a safe, secure and easily maintained facility.

### Benefits of Daylighting

There are several advantages to the use of daylight in schools:

### Academic Performance

Studies indicate that well-designed daylighting is associated with enhanced student performance, evidenced by 13–26% higher scores on standardized tests, while poor daylighting design has been shown to correlate with reduced student performance (Heschong Mahone Group 1999). It makes sense that students and teachers perform better in stimulating, well-lit environments. Daylighting can provide high quality light, stimulating views and an important communication link between the classroom and adjacent spaces.

### Energy Savings

Daylighting can save energy and reduce peak electricity demand if electric lights are turned off or dimmed when daylight is abundant. Nationally, K-12 schools spend more than $6 billion a year on energy. In California about 40% of school building energy use is attributable to just electric lighting. Daylighting per se, however, saves no energy unless the electric lighting system is appropriately controlled. To be effective, daylighting must be thoughtfully designed, avoiding glare and overheating, and must include dimming or switching of the electric lighting system, preferably with automatic photocell control. The design of systems for supplementary electric lighting and controls is addressed in the chapter on electric lighting.

### Better Light

Daylight provides the highest quality light source for visual tasks. It enhances the color and visual appearance of objects, and helps students to see small details better.

### Connection to Nature

Daylight provides a connection to the natural world by supplying information on time of day, the season and weather conditions. In doing so, it enriches the learning environment and may also help to make lessons more memorable.

### Improved Health

Views provided by windows contribute to eye health by providing frequent changes in focal distance, which helps to relax eye muscles. Daylight, whether associated with a view or not, may also reduce stress for both students and teachers. Recent research in Sweden showed that work in classrooms without daylight "may upset the basic hormone pattern, and this in turn may influence the children's ability to concentrate or co-operate, and also eventually have an impact on annual body growth and sick leave."[18]

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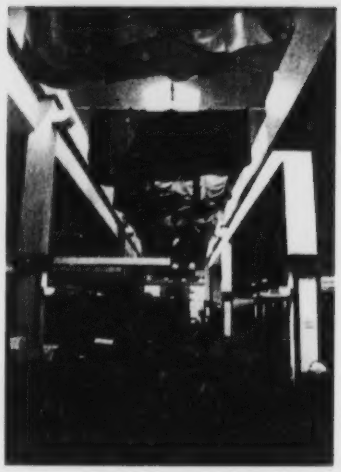
[18] Kuller and Lindsten. 1992. *Journal of Environmental Psychology* 12:305-317.

**Environmental Education**

Windows and solar gain through windows can present opportunities to teach how the sun moves through the sky and how daylight can be controlled by carefully designed overhangs and other shading devices. These observations can form part of an experiential learning unit for environmental education as students plot the movement of the sun on a sundial or across a school yard wall. Control of electric light in response to daylight may also be one of the "treasures" found in the Energy Treasure Hunt, a pilot program (sponsored by Department of Energy's Rebuild America, the U.S. Environmental Protection Agency, Pacific Gas & Electric and others) in several northern California schools to educate students about issues pertaining to energy and efficiency.



*Cameron Park Library, Peter Wolfe Architect. A skylit library provides a stimulating yet peaceful environment. Colorful banners enliven the space while blocking glare from the skylights and helping to diffuse the daylight. Photo courtesy Lisa Heschong*

## Basic Daylighting Principles

The following six principles provide fundamental guidance in designing daylit schools. These are described in more detail below.

1. Prevent direct sunlight penetration into space.
2. Provide gentle, uniform light throughout space.
3. Avoid creating sources of glare.
4. Allow teachers to control the daylight with operable louvers or blinds.
5. Design the electric lighting system to complement the daylighting design, and encourage maximum energy savings through the use of lighting controls
6. Plan the layout of interior spaces to take advantage of daylight conditions.

### 1. Prevent Direct Sunlight Penetration

One of the delights of daylight is that it changes in quality throughout the day and with each season. The daily and seasonal path of the sun is the prime determinate of sunlight availability, while the presence of clouds and moisture in the air affect the quality and intensity of light from the sky. It is essential that designers understand the basic principles of solar orientation, climate conditions and shading systems to design successful daylit buildings.

*Sunlight Versus Daylight*

Direct beam *sunlight* is an extremely strong source of light, providing up to 10,000 footcandles of illumination. It is so bright, and so hot, that it can create great visual and thermal discomfort. *Daylight*, on the other hand, which comes from the blue sky, from clouds, or from diffused or reflected sunlight, is much more gentle and can efficiently provide excellent illumination without the negative impacts of direct sunlight. Good daylighting design typically relies on maximizing the use of gentle, diffuse daylight, and minimizing the penetration of direct beam sunlight. In general, sunlight should only be allowed to enter a space in small quantities, as dappled light, and only in areas where people are not required to do work.

*North versus south windows. South windows are shaded from direct sun, but receive daylight reflected off of concrete walk and white painted overhangs. North windows are large and unshaded. Photo courtesy Lisa Heschong*

The best daylighting designs are initiated early in the design process of new buildings. The first step in good daylighting design is the thoughtful orientation of the buildings on the site and orientation of the fenestration openings. A carefully oriented building design will allow maximum daylight while minimizing unwanted solar gains. It is easiest to provide excellent daylight conditions using north-facing windows, since the sun only strikes a north-facing window in early morning and late evening during midsummer. South-facing windows are the next easiest because the high angle of the south sun can be easily shaded with a horizontal overhang. East- and west-facing windows are more problematic because when the sun is low in the sky, overhangs or other fixed shading devices are of limited utility. Any window orientation more than 15 degrees off of true north or south requires careful assessment to avoid unwanted sun penetration.

For sidelighting, carefully designed shading devices both inside and outside the building can limit direct sun penetration while allowing diffuse daylight. For toplighting, avoid direct sun by using glazing that diffuses the sunlight, or by reflecting it off baffles, louvers or light well walls. The sections on Sidelighting and Toplighting below give strategies for the design of shading devices for optimum performance.

### 2. Provide Gentle, Uniform Illumination

Daylight is most successful when it provides gentle, even illumination throughout a space. Evenly diffused daylight will provide the most energy savings and the best visual quality. Achieving this balanced diffuse daylight throughout a space is one of the greatest achievements of a good daylight designer.

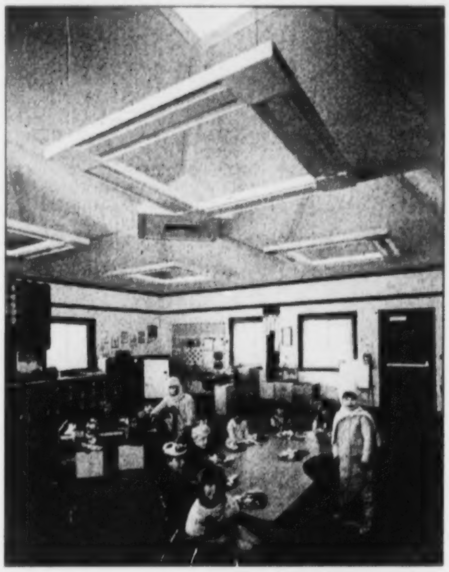
It is easiest to achieve uniform daylight illumination from toplighting strategies that distribute light evenly across a large area. The next best approach is to provide daylight from two sides of a space with a combination of view windows and high windows, preferably no more than 30 to 50 feet apart. Combinations of sidelighting with toplighting can also be successful in providing uniform illumination levels. The most challenging condition is a room with windows on only one side. There, daylight illumination levels will be very high right next to the window and drop off very quickly. Various strategies to distribute light deeper into the space are available, but require more design skill and construction cost.

Daylight can most easily be used to provide a base level of illumination throughout a space, referred to as the ambient illumination. This is often on the order of 20 to 30 footcandles throughout the space. Individual work areas can then be highlighted with electric task lights to bring the illumination levels in specific areas to higher task level requirements, such as 50 or 75 footcandles. Alternatively, if the daylighting fenestration area is increased to provide the higher task illumination for most of the day, the electric lighting energy savings will be maximized while heating and cooling costs may increase. The best daylighting designs balance these energy costs with the desired lighting quality.

*Walls, Ceilings And Other Reflective Surfaces*

The arrangement of reflective surfaces that help to distribute the light are just as important as the arrangement of daylight openings for providing gentle, uniform illumination. Whenever possible, place daylight apertures next to a sloped or perpendicular surface so the daylight washes either a ceiling or a wall plane, and is reflected deeper into the space. It is essential to recognize that walls and ceilings are part of the daylighting design. For greatest efficiency and visual comfort, they should be painted white, or a very light color. Even pastel-colored paint absorbs 50% of the light that strikes it, correspondingly reducing daylight levels. Saturated colors should be used only in small areas, for accents or special effects.

Advanced daylighting designs take advantage of additional exterior and interior reflecting surfaces to shape the distribution of daylight in the space. Light-colored walkways and overhangs can help reflect daylight. Light shelves can be used to bounce daylight deeper in the space (see Guideline DL3), or a series of reflective or refractive surfaces built into the glazing itself can redirect sunlight onto the space's ceiling. These approaches are integral to the architecture of the building and are designed differently for each cardinal orientation. For example, classrooms may have light shelves on the south side of the building, but none on the north. In this way, the design is "fine tuned" to optimize the daylight delivery for each orientation.

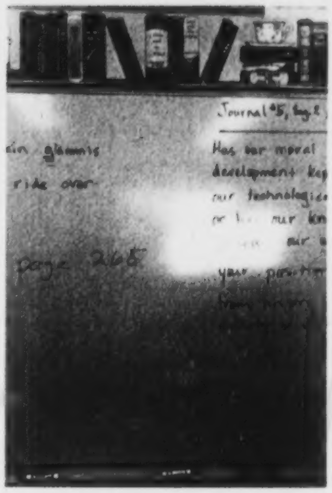


*Deeply coffered ceiling helps to diffuse light from four skylights. Note the even wash of illumination on classroom walls. There are no electric lights on in this photo. Photo courtesy SunOptics*

### 3. Avoid Glare

Excessively high contrast causes glare. Direct glare is the presence of a bright surface (for example, a bright diffusing glazing or direct view of the sun) in the field of view that causes discomfort or loss in visual performance. This can have negative effects on student and staff performance. A recent study showed that skylights that admitted direct sun (and presumably glare) into classrooms correlated with a *decrease* in student performance on standardized tests (Heschong Mahone Group 1999). Eliminate glare by obscuring the view of bright sources and surfaces with blinds, louvers, overhangs, reflectors, and similar devices.

Placing daylight apertures next to reflective surfaces reduces glare in addition to distributing the daylight more evenly. It brightens interior surfaces to reduce their contrast with the bright glazing surface. If washing a wall with daylight is not possible, some glare reduction can be achieved by splaying window reveals and skylight wells. Blinds or drapes can also reduce contrast by controlling the amount of brightness at the windows, and diffusing the light. Punched windows (simple holes in the middle of a wall) represent the worst scenario for glare and are not recommended.



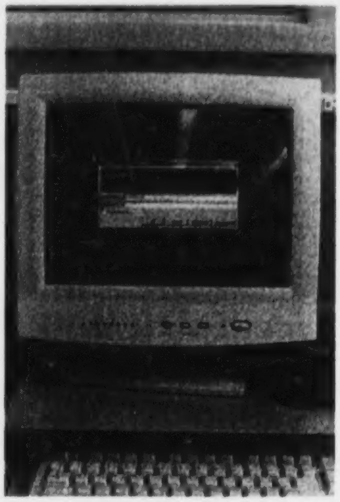
*Glare from windows or light fixtures reflecting off of shiny surfaces, such as computer screens or whiteboards, can reduce student performance. Photo courtesy Lisa Heschong*

Glare can also occur when daylight strikes a reflective surface like a computer screen or a whiteboard and produces shiny reflections that make it difficult or impossible to see. You can predict when these reflections will be a problem by placing an imaginary (or real) mirror on the screen or whiteboard and seeing if any bright light sources or surfaces are visible in the mirror. If they are visible, then reorient the screen/whiteboard or redesign the apertures to eliminate their reflection in the surface.

*VDT Screens*

When video display terminals (VDTs) are located in daylit spaces, the designer must take great care to minimize daylight reflections from the VDT screen. This problem is especially acute when the computer screen is oriented so that the screen is facing the daylighting aperture (that is, the student's back is to the window or skylight). Under these conditions, reflected glare may completely wash out the screen, making work impossible without completely closing window blinds or

*Horizontal blinds allow control of brightness from lower view windows. Note that high clerestory windows have no blinds so that daylight can reach deep into classroom. Most classrooms do not need complete black out capability for viewing of modern video equipment. Photo courtesy Barbara Erwine*



*Reflections of luminaires in computer screens can cause veiling glare. Careful lighting and daylighting design avoids these problems. Photo courtesy Lisa Heschong* drapes. If the VDT screen is located so that the screen viewing orientation is parallel to or 45 degrees to the windows (see figure on left), reflected glare poses less of a problem and, if present, can usually be reduced by using polarizing filters or meshes attached directly to the screen.

### 4. Provide Control of Daylight

Daylight is highly variable throughout the day and the year, requiring careful design to provide adequate illumination for the maximum number of hours while contributing the least amount possible to the cooling load. The ideal daylighting design would have variable apertures that respond to changes in the availability of daylight. The apertures would become smaller when daylighting is abundant and larger on cloudy days or at times when daylight is less available. While electrochromic glazing may permit variable daylighting apertures in the future, with today's technology, the size of the aperture and its transmission are fixed. The principal means of control is through the use of shades or blinds located inside or outside the window.

Teachers should have easy access to controls for these shades or blinds to adjust light levels as needed throughout the day. These systems should be reliable and easy and economic to clean and repair. Manually operated controls are slightly less convenient but also less expensive and less likely to need repair. Avoid the use of moveable exterior shades; they are exposed to weather conditions that may degrade their performance. Ensure that fixed exterior shading devices are sloped slightly so they drain water.

### 5. Integrate with Electric Lighting Design

The daylight and the electric light systems should be designed together so they complement each other to create high quality lighting. This requires an understanding of how both systems deliver light to the space. For example, if daylight lights the two sidewalls, electric light may be used to highlight the teaching wall. The Design and Analysis Tools section later in this chapter discusses tools to help visualize the overall light distribution in the space.

#### *Color*

Daylight is a "bluer" light source than most electric lighting. Fluorescent lights that are designed to match the color of incandescent light will appear yellow in comparison with daylight. The "color temperature" of a light source is a number that describes its relative blueness or yellowness. When mixing daylight and electric light, most designers choose fluorescent lamps with a color temperature of 3500°K to 4100°K or even higher.

#### *Controls*

Daylighting is also more thermally efficient than electric lighting. This means that the cooling load created by daylighting illumination is much lower than that created by electric lighting providing the same light level. Since electric lighting is a major contributor to the cooling load in schools, substituting daylight for electric lighting reduces cooling costs as well as lighting costs. But these energy savings will only be achieved if the electric lights are turned off or dimmed in response to the daylight.

The electric lighting should be circuited and controlled to coincide with the patterns of daylight in the space, so that the lights can be turned off in areas where daylight is abundant and left on where it is deficient. Controls can either be manual or automatic. Automatic controls use a small photosensor that monitors light levels in the space. Manual controls are substantially less expensive, but need to be convenient and well labeled to ensure their use. Automatic controls guarantee savings, but are more expensive and must have overrides so the teacher can darken the room for AV use. Lighting controls are discussed in more detail in the chapter on Electric Lighting and Controls.

*Lighting Controls, Oakridge High School: Automatic photosensor controls turn off first bank of lights next to skylight well. The light fixtures are arranged parallel to skylights to left and windows (out of picture) to right, while whiteboard is located perpendicular to windows and skylights. Photo courtesy Lisa Heschong*

### 6. Plan the Layout of Interior Spaces

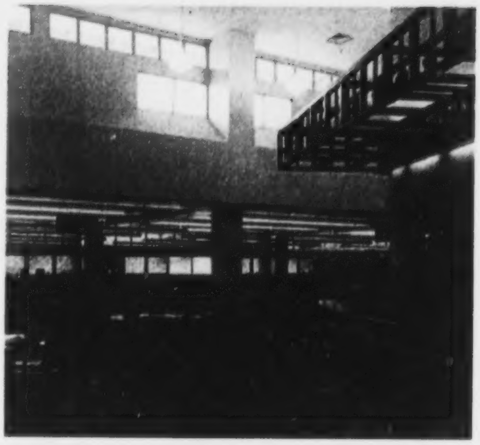
Successful daylighting designs must include careful consideration of interior space planning. Since daylighting illuminance can vary considerably within the space, especially with sidelighting, it's important to locate work areas where there is appropriate daylighting. Perhaps more importantly, visual tasks (especially the teaching wall) should be located to reduce the probability of discomfort or disability glare. In general, work areas should be oriented so that daylighting is available from the side or from above. Facing a window may introduce direct glare into the visual field, while facing away from a window may produce shadows or reflected glare.

## Sidelighting vs. Toplighting

The location, orientation and size of the daylighting apertures is of paramount importance, as is the selection of the glazing materials used and how they are shaded from direct sun. When possible, it's always better to locate daylighting apertures in the ceiling plane—a strategy known as toplighting. This reduces the likelihood of glare and allows for more even distribution of daylight within the space. Toplighting, of course, can only be provided for one-story buildings or for the top floor of multi-story buildings. The other basic strategy, sidelighting, allows daylight to enter through windows in vertical walls. With windows, uniform illuminance is more difficult to provide, as there is always more light next to the window. Glare is also more difficult to control. But there are design techniques that can substantially reduce problems associated with sidelighting.

## Sidelighting

The basic sidelighting pattern provides windows on one or more walls of the space. The depth of daylighting penetration from vertical windows is largely dependent on the height of the window head (that is, the top of the window). For a simple sidelighting scheme, a rough rule of thumb is that useable daylight will be available about 1.5 times the window head height. So for good daylight delivery, sidelighting windows should be located as high as possible in the wall. However, to provide exterior views, windows need to be at eye level. Since these requirements clearly conflict, advanced daylighting designs differentiate between the functions of view and task daylighting, frequently providing separate windows for each of these.



*Sidelighting: Library receives daylight from two sidelighting strategies: 1) view windows at perimeter, and 2) high clerestories that bring daylight into the center of the space.*

The orientation of a sidelighting aperture strongly affects the quantity, quality and distribution of daylight. For sidelighting and no shading, north-facing windows provide the most even illuminance. The quantity of light is diminished, but a larger aperture will compensate, providing adequate and more even illumination.

### *Exterior Shading Strategies*

Shading devices for sidelighting strategies minimize solar gains and glare, and can also be designed to increase illumination levels. Shading devices—both overhangs and fins—can be either opaque or translucent, and solid or louvered. It's best to place shading devices outside the glazing to stop solar gains before they hit the window and to reduce potential glare from bright window views. Exterior overhangs should be deep enough to minimize direct sun on the window for the hottest hours of the day during the cooling season. For south-facing windows in sunny (clear sky) climates with very high air-conditioning loads, a good rule of thumb is to design the overhang with a shading cutoff angle about equal to 90 degrees minus the site latitude. This provides full shading between March 21 and September 21. Many areas are likely to experience their hottest weather in September, and so still need full shading that time of year. Overhangs for climates with lower air-conditioning loads and/or more summer overcast can increase this angle by 5–15 degrees. Overhangs or fins for windows facing east or west don't lend themselves to simple rules of thumb and should be carefully designed for the specific site, climate and space. North-facing windows usually don't need exterior overhangs or fins, but may occasionally need interior blinds or louvers to control glare.

### *Interior Shading Strategies*

Interior shading devices for windows reduce solar heat gain somewhat (by reflecting solar gain back out through the glazing) but are most effective at controlling glare. The most common interior glare control devices are horizontal mini-blinds, vertical blinds, shade screens and curtains. Mini-blinds positioned between the panes of glass in double-glazed fenestration do not have to be cleaned and may have the lowest maintenance costs, but their initial cost is substantially higher. They can also pose replacement problems if a window is broken. Interior shading devices can also be used for security purposes to obscure the view of room contents when a space is unoccupied. Many school spaces will also require blackout shades. All these operable devices should have robust, reliable controls that are easily accessible to the teacher. However, operable louvers, blinds and drapes are frequently left in a non-optimal daylighting setting—either fully closed or fully open. Systems that have fixed louvers or settings for the daylight glazing and operable glare control for view glazing will be more likely to deliver dependable daylight throughout the year.

### *Landscaping*

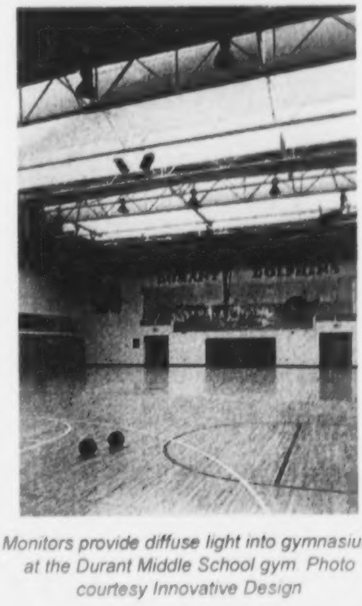
Daylight is also affected by obstructions on the site, such as trees and other buildings. Landscaping can serve an important shading and sun control function if it is strategically placed or incorporated into a trellis device. Deciduous trees and vines positioned to the south of a window are extremely useful for providing shade during overheated summer months while admitting more sun in areas with cold or overcast winters. Evergreens provide shade year-round in consistently overheated climates. They are also useful for blocking low east and west sun.

## Toplighting

Lighting distribution quality for toplighting schemes is superior to anything that can be provided by sidelighting; therefore, toplighting should be implemented for most one-story building applications. Several skylight configurations have been used successfully in daylighting designs, including "sawtooth" monitors, vertical and splayed wells, and light boxes.

Figure  shows four toplighting patterns: skylights, clerestory windows, light boxes and sawtooth roof monitors. The pattern of illuminance created by each toplighting approach is illustrated for one or more orientations.

Proper spacing of skylights is important for uniform daylight distribution. The space between the skylight wells should not exceed 1.5 times the floor to ceiling height. When the well is broadly splayed, the vertical distance should be measured to the top of the splay. As shown in Figure , the pattern of daylighting illumination is much more uniform with all the



*Monitors provide diffuse light into gymnasium at the Durant Middle School gym. Photo courtesy Innovative Design* toplighting patterns when compared to the sidelighting patterns. The north-facing sawtooth roof monitor produces the most uniform pattern of daylighting illuminance. This pattern is also excellent at controlling solar gain into the space and at minimizing the load on the air-conditioning system. Clerestory windows also provide excellent daylighting distribution, especially when they face north.

For toplighting schemes in all critical task areas, direct sun is a potential glare source and should be diffused by either diffusing glazing or reflection off a diffusing surface. This minimizes the glare potential, eliminates "hot spots" and spreads the daylight more effectively in the space. Diffusing glazing materials are discussed in the section on Fenestration Products below.

### *Horizontal vs. Vertical Glazing*

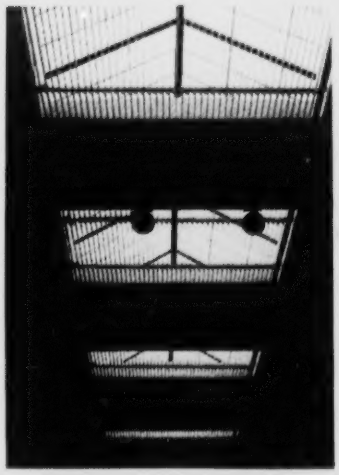
Toplighting designs can have either horizontal or vertical glazing. Because the sun is higher in the sky in the summer than in the winter, toplighting schemes with horizontal glazing receive more direct sun in summer (when it is not needed) than in winter (when it is needed). The opposite is true with south-facing vertical glazing schemes; so for heating and cooling, vertical glazing is inherently more energy efficient than horizontal during clear sky conditions. However, in overcast skies, the sky is brightest straight up, so horizontal glazing is more efficient at delivering daylight to the space. A pyramid or arched shaped diffusing skylight may also be more effective at collecting daylight during the very low sun angles of early morning or late afternoon. Another consideration is cost. Horizontal skylight designs can be much less expensive than vertically glazed roof monitors, and may be easier to integrate with HVAC and structural systems. The final decision for horizontal or vertical glazing is a balance of these concerns for the specific building and climate. Whichever is selected, the design must be optimized to deliver low glare daylight to the space while minimizing energy impacts.

### *Solar Orientation*

The design of vertical toplighting glazing is complicated by the fact that it has different performance characteristics for each solar orientation. For orientations that receive direct sun, the glazing area should provide abundant daylight, but not so much that solar gains create unnecessary cooling loads. Glazing apertures facing south may be sized smaller if they receive high levels of direct sun on clear days which is diffused with diffusing glazing or baffles. North-facing glazing will receive lower, more even levels of diffuse sky light and may be sized larger than south facing apertures to gather similar light levels. East and west orientations show large variations in light levels throughout the day and should be avoided. The individual daylighting guidelines give recommended glazing areas for various toplighting schemes.

*Toplighting Shading Strategies*

Shading for monitors may not be needed if the light well design prevents direct sun from entering the space. Exterior shading devices for skylights are available, but not recommended due to maintenance problems. Rooftop devices are usually exposed to more severe weather, dust, and debris but have less maintenance supervision than windows. Sturdy, dependable performance is an essential criterion. Thus, it is a good idea to protect any shading or operable equipment for skylights below at least the first layer of skylight glazing. Some skylight manufactures offer fixed or operable louver options for sun and daylight control, to reduce both solar gain and excessive daylight. Others offer movable insulation devices that can be operated, either manually or automatically, to reduce both solar gain and nighttime heat losses.



***Linear skylight in multipurpose room includes electrically operated louvers to reduce brightness when needed.** Photo courtesy Lisa Heschong*

*Structural Considerations*

All toplighting schemes represent penetrations through the roof diaphragm, which is often a critical part of the building's structural system, designed to stiffen the building and resist forces that tend to twist the structural frame. This structural diaphragm can have a certain number and size of holes in it and still continue to function. But at some point, additional holes will weaken its strength, limiting the size and location of toplighting apertures. However, if more toplighting apertures are desired than allowed by the structural system, the project's structural engineer may be able to devise ways to strengthen the diaphragm to allow additional penetrations.

The light well connecting the toplighting aperture with the space below may also intersect HVAC ducting, electric lighting layouts, and fire sprinkler systems. Careful coordination of the structural and mechanical designs will ensure compatibility among these systems.

## Fenestration Products

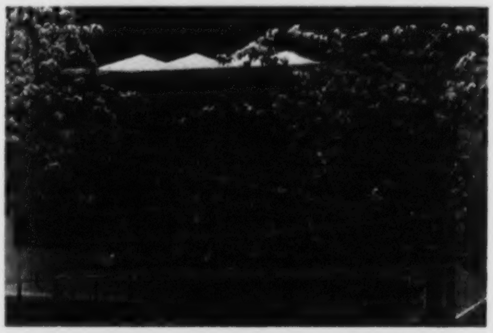
High-performance fenestration features include double glazing, low-emissivity coatings, and blue/green tints. These have become a very important means of energy conservation in modern construction to reduce both thermal losses and solar gains. Fenestration has three principal energy performance characteristics, which have been identified by the National Fenestration Rating Council (NFRC) to be tested and labeled on manufactured windows: Visible light transmittance, solar heat gain coefficient, and U-factor. Site-built windows and skylights may or may not have such tested information available.

- *Visible light transmittance (VLT)* is the fraction of light that is transmitted through the glazing. Light is that portion of solar radiation that is visible, that is, it has a wavelength between about 380 and 780 nanometers. Single clear glass has a VLT of about 0.9, while highly reflective glass can have a VLT as low as 0.05. The quantity of daylight that enters a window or skylight is directly proportional to the VLT. In general, VLT should be as high as possible, as long as it does not create glare or other visibility problems.

- *Solar heat gain coefficient (SHGC)* measures the solar heat gain through a window. A window that has no solar gain would have a SHGC value of zero, while a perfectly transmissive glazing would have a SHGC of 1.0. These extremes are both theoretical concepts that are not possible in the real world. Except in passive solar applications where solar heat gain is desired, everything else being equal, glazing materials should be selected with the lowest possible SHGC. However, glazing materials with a low SHGC (like dark gray and bronze tints) may also have a low VLT, so the challenge is to identify specialized "selective" low-e products and blue/green tints that combine the lowest SHGC with the highest VLT.
- *U-factor* measures the heat flow through a window assembly due to the temperature difference between the inside and outside. The lower the U-factor, the lower the rate of heat loss and of heating energy consumption. Everything else being equal, the U-factor should be as low as possible. The fenestration frame and glazing edge spacers degrade the U-factor of an insulated glass assembly. So two U-factors are frequently specified: the center of glass (COG) value, which is the U-factor measured at the center of the assembly, and the whole window value, which is the overall U-factor of the glazing plus the spacer and frame system. (The whole unit value will be lower than the COG value.). Single-pane windows typically have a U-factor in the range of 1.0 to 1.2 (COG); double pane windows range from 0.65 to 0.45 (COG). With low-emissivity (low-e) coatings, inert gas fills and multiple glazings, the U-factor can be as low as 0.1 (COG).

Other glazing considerations include diffusion, transparency, and durability:

- *Diffusion and Transparency:* Transparent glazing materials provide views, but diffuse materials can spread daylight better in the space. Diffusion is one of the most important characteristics in selecting a skylight. Good diffusing glazings maximize the spread of light in the space and minimize "hot spots" and glare. Diffusion may be accomplished by using a white pigment, a prismatic surface or embedded fibers. Unfortunately, specifications on diffusion properties are rarely available for fenestration products. Thus, samples of diffusing glazing materials should be visually evaluated to see how well they diffuse direct sunlight. A simple test is to place the product in the sun and see if it allows your hand to cast a shadow. A fully diffusing material will blur the shadow beyond recognition and will not concentrate the sunlight into local hot spots. Note that diffusing glazing placed in direct sunlight can be glaring bright if it is within the field of view. It should be placed above the direct line of sight or be obscured by baffles.



*Pyramid skylights on experimental portable classroom design integrates skylights into a high efficiency modular design. Photo courtesy Lisa Heschong*

- *Durability:* Characteristics such as UV degradation (yellowing and other aging effects), structural strength, scratch resistance, breaking and fire resistance, along with replacement cost and availability, should be considered in selecting a glazing material.

The fenestration frame holds the glazing material in place and forms the structural link with the building envelope. The frame and the spacer between the glazing panes in multiple glazed units form a thermal short circuit in the insulating value of the fenestration. This degradation of the U-factor at the fenestration perimeter can be minimized with high performance frame and spacer technologies now available. This is important both for energy conservation and the potential for condensation on the frame.

Frames are available in metal, wood, vinyl, composite and fiberglass. Metal frames conduct the most heat and must have a thermal break for good performance. Insulated vinyl and fiberglass frames have the lowest U-factor. The National Fenestration Rating Council has established a rating system to evaluate the whole window performance including the frame, spacer and glazing. The whole-window U-factor, VLT and SHGC is shown on a label attached to all rated windows. Rated windows should be purchased for all school projects and frame/spacer performance should be compared based on these overall ratings. Site-built windows and skylights will not have these ratings available.

## Design and Analysis Tools

There are three general categories of tools for evaluating daylighting and fenestration: physical models, lighting computer simulation programs and whole building energy simulation programs.

### Physical Models

Physical scale models are probably the easiest and most intuitive way to understand daylighting design options. Scale models can be easily built that quickly and accurately illustrate the daylighting conditions created by any given design. They also help nonprofessionals, such as teachers and parents, to see lighting quality issues directly, and understand why one design might work better than another. Photographs of the interior of scale models are an easy way to record the impacts of various design options. Many daylighting text books include a chapter on the construction and testing of daylight models. An excellent training video—Daylight Models, available from the Lighting Design Lab in Seattle—also describes how to build and test these models.

Daylighting models can also be used for numerical analysis. The models may be tested either outside under real sky conditions or in artificially constructed overcast sky and direct sun simulators. Small light measuring devices (photocells) can be used to record light levels within the model. Sun simulators (heliodons) can be set to represent the correct sun angle for the site latitude and hour of day and are used to visualize the movement of light during a typical day. Measurements in a simulated sun or sky are more reproducible than in the real sky, which is constantly changing. Several California universities and electric utilities, including the Pacific Energy Center in San Francisco, have sun and overcast sky simulators and associated video equipment and photocell arrays.

### Lighting and Daylighting Computer Simulations

Electric lighting and daylighting computer simulations such as Radiance, Superlite, LumenMicro and Lightscape give information about the distribution of lighting in spaces with contributions from windows and skylights as well as electric lighting systems. Unlike the energy simulation programs described below, these programs produce results for a single instant in time. Multiple calculations are needed to study varying sky and solar conditions. These computer-based tools give light level values and gradients for both daylight and electric light across the space. Some of these tools also produce realistic renderings of lighting within the space, which may be linked to generate an automated "walkthrough" of the space for a particular day and time or to simulate the daylight variations through the hours of the day. The programs that are easiest to use may be constrained by the complexity of shapes they can simulate. The more complex programs can simulate almost any room shape or material, but require significantly more expertise and modeling time.

### Whole Building Energy Simulations

Whole building energy simulation tools such as DOE-2, EnergyPlus, BLAST and Energy 10 and spreadsheet estimating programs like SkyCalc consider all aspects of the fenestration's impact on building energy use, including solar gains, impact on HVAC equipment sizes, and reduction of electric lighting energy. Many of the energy simulation programs have user-friendly interfaces to make it easier to construct models and evaluate results. Most of these tools have simplified daylighting simulation algorithms that may not accurately represent daylight levels from complex designs (like light shelves). For these designs, daylight predictions from one of the computer simulations mentioned above may need to be input to the energy program to accurately predict daylight's potential to save energy by turning off or dimming electric lights.

## Other Design Considerations

The on-line Appendix that supports the Best Practices Manual has details of additional design considerations, including the following:

- Natural Ventilation
- Noise Control
- Radiant Comfort
- Safety and Security
- Air and Water Leakage
- Condensation
- Replacement
- Maintenance
- Fire Resistance

## Applicable Codes

The California Energy Efficiency Standards for Nonresidential Buildings (Title 24) limit the window-wall ratio to 40% of the exterior wall. Beginning in mid-2001, the code will require high performance glazing, including thermal break frames and low-e coated double glass, although the requirements vary somewhat with climate. The standard does not require daylighting or daylighting controls, but it does offer credits when automatic controls are installed.

## Resource Efficiency

In terms of energy performance, windows are one of the most important considerations in building design. Windows also provide an opportunity to address other environmental objectives, including materials efficiency, indoor air quality, and pollution prevention during manufacturing.

To achieve materials efficiency, windows are now being manufactured with durable alternatives to wood frames and sashes, including options made with post-industrial waste. Unfortunately many of these products can contribute to pollution during manufacture, and possibly even to indoor air quality problems. For now, the best environmental performance strategy is to select durable frame and sash options that enhance energy performance and meet programming and daylighting needs. Table 16 lists currently available options that are environmentally preferable from a materials efficiency perspective.

*Table 16 – Strategies for Constructing Resource Efficient Fenestration Systems*

| *Window Frame and Sash* | *Strategies* | *Environmental Benefits & Considerations* |
|---|---|---|
| Wood | Select windows produced with wood certified by Forest Stewardship Council (FSC), Scientific Certification Service (SCS). | Prevents degradation to forest and wildlife habitat; wood can be high maintenance. Good energy performance. |
| | Specify factory-applied finish. | Typically more durable than field-applied. More controlled finishing environment prevents pollution. |
| Wood and Plastic Composite | Durable options combine wood fiber and post-consumer waste plastic, and combine recycled PVC scrap, virgin PVC, and fiber from recycled wood scrap. | Utilizes industrial waste, stretching the wood supply. Very durable and low maintenance. Manufacture of PVC contributes to pollution, however. Good energy performance |
| Vinyl | Vinyl frames include foamed PVC insulating core. | Low maintenance. Needs no paint. Manufacture of PVC contributes to pollution, however and high co-efficient of thermal expansion can lead to premature failure of seal. Excellent energy performance. |
| ABS Plastic | | Low maintenance. Needs no paint. Manufacture contributes to pollution however, and high co-efficient of thermal expansion can lead to premature failure of seal. Moderately good energy performance. |
| PVC Plastic | | Low maintenance. Manufacture contributes to pollution. Manufacture contributes to pollution, however, and high co-efficient of thermal expansion can lead to premature failure of seal. |
| Fiberglass | Pultruded fiberglass frame members have a hollow profile usually insulated with fiberglass or polyurethane foam. | Promotes durability. However difficult to recycle. Emissions contribute to indoor air quality problems and manufacture contributes to air pollution. Moderately good energy performance. |
| Metal | Specify durable, factory-applied finishes, anodized, polyvinlidene fluoride, and siliconized polyester. | Promotes durability and reduces potential pollution on site. Energy-intensive production, however. (Not the best energy performance. Do not use metal frames that lack thermal break.) |

Source: GreenSpec: The Environmental Building News Product Directory and Guideline Specifications

For specific product recommendations, see GreenSpec: The Environmental Building News Product Directory and Guideline Specifications, http://www.buildinggreen.com and OIKOS's Redi Guide (Resources for Environmental Design Index), Iris Communications, 800-346-0104, http://www.oikos.com

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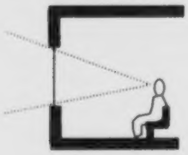
# Guideline DL1: View Windows



### Recommendation

Provide access to exterior views through view windows for all interior spaces where students or staff will be working for extended periods of time.

*View windows at Camaron Library expand the space outward and connect the reading area with the natural landscape. Lisa Heschong, photographer.*

| Applicable Spaces | | Climates | | When to Consider | |
|---|---|---|---|---|---|
| Classrooms | ■ | South Coast | ■ | Programming | ■ |
| Library | ■ | North Coast | ■ | Schematic | ■ |
| Mult-Purpose / Cafeteria | ■ | Central | ■ | Design Dev | ■ |
| Gym | ▨ | Mountains | ■ | Contract Docs | ▨ |
| Corridors | ■ | Desert | ■ | Construction | ▨ |
| Administration | ■ | | | Commissioning | ☐ |
| Toilets | ☐ | | | Operation | ☐ |
| Other | ☐ | | | | |

### Description

A view window is vertical glazing at eye level, which provides a view to the exterior or interior adjacent spaces.

### Applicability

View windows are essential in all school spaces (except spaces requiring visual privacy) to provide relaxing views and information about exterior natural conditions, and also to allow people outside of a space to view and connect with activities inside. They are applicable to all climate regions and should be planned in the schematic design phase.

### Applicable Codes

The California Energy Code does not require that view windows be installed. However, the code does specify the minimum performance of fenestration products and it limits window area to a maximum of 40% of the exterior wall area.

### Integrated Design Implications

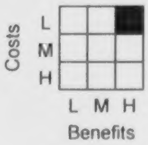
- **Balance with other program needs:** View windows serve a broad range of important functions for view, social communication, egress, ventilation and energy conservation (See Benefits below). However view windows are often inefficient at supplying working daylight to the space. Since overall glazing area is limited by code, the square footage of view windows will reduce the allowable area for windows and skylights placed higher in the wall and ceiling that can be designed to deliver more useful daylight across the space. View windows also decrease valuable classroom wall space and pose potential acoustic and vandalism problems. A balance should be achieved among these conflicting needs.
- **Integration with mechanical ventilation:** Operable view windows should be used to naturally ventilate the space and reduce mechanical ventilation needs. Evaluate prevailing wind conditions to assess the feasibility. A statistical analysis of 650 schools by the Florida Solar Energy Center found a

strong correlation between the presence of operable windows and a decrease in indoor air quality complaints.[19]

- **Integration with HVAC:** View windows should decrease overall seasonal heating and cooling loads on the building if they are oriented, glazed and shaded correctly. This can reduce the initial size of the HVAC system and annual energy costs. The analysis of Florida schools noted above also found that the presence of windows strongly correlated with an overall reduction in total building energy use.
- **Thermal Comfort:** Window surfaces that are considerably above or below the mean radiant temperature of other room surfaces will be uncomfortable for occupants adjacent to them. Shade the windows, use high performance glazing and design HVAC to minimize radiant thermal discomfort.
- **Space Planning**: View windows should be oriented relative to the location of stationary tasks, such as desks, teaching wall, computer locations, and reading areas. Avoid reflected glare from windows in computer screens or on whiteboard surfaces. The best classroom location for view windows is perpendicular to the teaching wall
- **Design Phase:** To function well, view windows must be at eye level, glare free, oriented toward views that will not distract occupants, and designed to reduce building energy loads. A requirement for view windows should be identified in the building program; their location and design objectives should be determined in the early phases of schematic design.

## Costs

Costs for view windows are typically low. View windows are (or should be!) standard practice for classrooms. The incremental cost of energy-efficient glazing ranges from $0.75 to $2.50 per square foot of glass. Daylight energy savings from view windows are negligible because the shading elements required to minimize glare usually render them unreliable for reducing electric light consumption.



## Benefits

View windows provide numerous benefits, serving a broad range of important functions for view, social communication, egress, ventilation and energy conservation

The outward views they provide are essential for mental stimulation and relaxation for eye muscles. Optometrists recommend access to long views for any sedentary workers (such as students) for frequent shifting of eye focal length, which promotes eye health and good vision. This may be especially important for young children while their eyes are still developing.

View windows provide occupants a connection with nature, weather, cardinal orientation and some natural light (though not evenly distributed across the space). Occupant productivity and connection with place may increase through the associated views. Studies have shown that the primary reason people prefer having a window is view, preferably a view of nature. Research suggests that natural views elicit positive feelings, hold interest and reduce fear and stress.20 Teachers have reported a reduction in stress levels when they have access to a relaxing view from their classroom (Heschong Mahone Group 1999)

View windows, especially on the first floor of school buildings, also provide an important social communication function, allowing teachers, administrators and parents to quickly assess what is going on inside a classroom. When installed with clear glass they are often used to display art work and current student projects, contributing to both pride, and awareness of other's efforts.

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[19] M. Callahan et. al. for FSEC by FSEC. June 199. Energy Efficiency for Florida Educational Facilities: 1996 Energy Survey of Florida Schools Final Report. Report # FSEC-CR-951-97. Submitted to Florida department of Education.

[20] Norris and Tillett. 1997. "Daylight and productivity: Is there a causal link?". Glass Processing Days Conference, Tampere, Finland (Sept.).

Operable view windows provide emergency egress and natural ventilation. A recent study has shown that natural ventilation in classrooms correlates with higher student test scores (Heschong Mahone Group 1999).

Well-designed view windows can reduce the overall building heating and cooling loads and north facing view windows can also deliver enough dependable daylight to reduce electric lighting loads with manual or photocontrols. Other orientations, however, often have blinds or curtains drawn. Thus, unless a view window faces north or has a head height over 8 ft, and separate glare control for at least 2 ft of the top glazed area, it should not be counted on to provide sufficient daylight to merit the installation of automatic photocontrols and reap predictable savings from reduced electric lighting use.

*View windows at RI library are separated from the daylight feature overhead and use lower transmission glass to reduce glare. Lisa Heschong, photographer.*

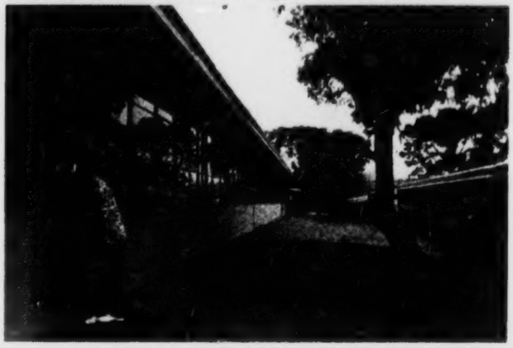
## Design Tools

The physical models and daylight simulation tools noted in the overview can be used to evaluate potential daylight levels, and energy programs can be used to understand building energy implications.

For critical view areas, access to views and view angles from various positions in the space can be evaluated graphically with scaled drawings or with the use of a scale physical model. For a physical model analysis, it is helpful to have a "lipstick" video camera head which can be moved around inside the model to record the views available at each location.

## Design Details

- **Orientation:** Orient view windows toward the north or south to avoid low angle east/west sun. Up to 15 degrees variance from true north or south is acceptable, but will reduce performance.
- **Shading devices:** Since view windows are within the occupants' normal field of view, the contrast between the bright window view and other interior surfaces is an important glare consideration. Use exterior shading devices(overhangs, fins, etc.) or landscaping to eliminate direct sun and reduce brightness. If this is not possible, use a lower transmission glazing adjusted for the window orientation (about 40% transmission for south windows, 30% for east/west windows and 60–85% for north windows). On south, east and west orientations, add an interior shade(shade screen, blinds or drapes)so the teacher can adjust brightness and sun penetration as needed.In general, visible transmission of view glazing should not be reduced below 30% in clear sky climates or below 50% in heavily overcast climates. If tinted glazing is used, evaluate its effect on distortion of colors (for example, the graying of greens and blues in the landscape) in both overcast and clear skies. Provide blackout capability for view windows as needed.
- **Reflectance:** Deep splayed walls or mullions will also reduce glare. Paint all surfaces near windows white or off-white to further reduce contrast between the brightness of the window and its surrounding wall. Place view windows adjacent to a perpendicular surface to reflect daylight onto adjacent surfaces. Adjacent to walls is best. Avoid



*View windows promote communication between interior and exterior spaces. Lisa Heschong, photographer.*

punched holes in walls, as they create the worst glare conditions.

- **Outside reflective surfaces:** Be aware of bright reflective surfaces outside the view window that may create glare when they are in sunlight. Reflected sun off a car windshield can be especially troublesome. Light-colored walls within view can also create glare sources when they are in direct sun. Plant hedges or trees to reduce the glare potential from these exterior sources.
- **Thermal comfort:** Window surfaces that are considerably above or below the mean radiant temperature of other room surfaces will feel uncomfortably cold or hot for occupants sitting next to them. In very cold or hot climates (desert, mountain and Central Valley), use double glazing with a low-e coating to maximize comfort and energy efficiency. Single glazing is sufficient for coastal climates.
- **Views:** In classrooms, orient views toward "passive" nature scenes. In administration areas, views may be oriented toward the school entry or other security concerns.
- **Teaching surface:** In classrooms, the teaching wall should be perpendicular to the window wall for best illumination.
- **Computer screen location:** Orient computers at a 45 degree angle from view windows to avoid glare from reflections of the window in the VDT screen. Flat screen computers and adjustable-angle LED screens also help to reduce glare.
- **Security:** Provide operable interior shades and/or laminated glass for security in ground level rooms that contain computers or other valuables.
- **Durability and accessibility:** Use sturdy mechanisms for all operable ventilation and shading devices. Make them easily accessible to the teacher and easily repairable.
- **Noise transmission:** Use double-glazing or laminated glass to reduce noise transmission.
- **Balancing with electric light:** If view windows are the only daylight apertures in the room, and they appear on only one wall of the space, balance their brightness in the room by washing other interior walls with electric light.

### Operation and Maintenance Issues

View windows should be washed on a schedule. Elements provided to reduce glare and allow blackout conditions (blinds, drapes, blackout shades, etc.) need to be cleaned and replaced over time. Give consideration to the robustness of operable shade mechanisms that are accessible to students. Coordinate selection of glazing materials with the maintenance staff to ensure ease of cleaning and replacement. Districts may have district-wide standards to ensure quick replacement of broken glass.

Design ventilation devices to prevent physical entry and any rain or maintenance water penetration.

### Commissioning

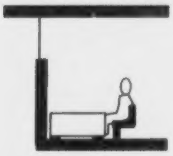
No commissioning should be required for view windows.

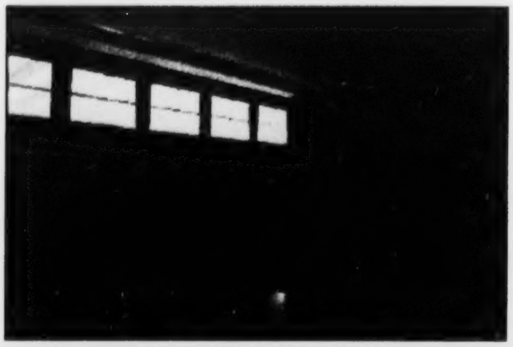
### Example(s)

### References / Additional Information

See the references section of the overview to this chapter.

# Guideline DL2: High Sidelighting—Clerestory





*Classroom with high clerestory window. Lisa Heschong, photographer.*

## Recommendation

Use high clerestories in perimeter walls to increase daylight delivery deeper in classrooms, offices, libraries, multipurpose rooms, gymnasiums and administrative areas.

## Description

High sidelighting clerestories are vertical glazing in an exterior wall above eye level (usually above 7 ft). Since the penetration of daylight from vertical glazing is about 2 times the window head height, moving the window higher in the wall increases daylight penetration in the space .

| Applicable Spaces | | Climates | | When to Consider | |
|---|---|---|---|---|---|
| Classrooms | ■ | South Coast | ■ | Programming | ■ |
| Library | ■ | North Coast | ■ | Schematic | ■ |
| Mulit-Purpose / Cafeteria | ■ | Central | ■ | Design Dev. | ■ |
| Gym | ■ | Mountains | ■ | Contract Docs. | ▨ |
| Corridors | ■ | Desert | ■ | Construction | ▨ |
| Administration | ■ | | | Commissioning | ☐ |
| Toilets | ■ | | | Operation | ☐ |
| Other | ■ | | | | |

## Applicability

High clerestory windows can be used in all school spaces to provide deep penetration of daylight. They are applicable to all climate regions and should be planned in the schematic design phase.

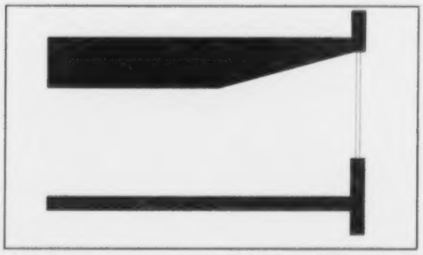
## Applicable Codes

The California energy efficiency code does not require that high clerestories be installed. However, the code does specify the minimum performance of fenestration products and it limits window area to a maximum of 40% of the exterior wall area.

## Integrated Design Implications

- **Design phase:** High sidelighting requires high ceilings and perimeter walls. North and (shaded) south orientations are preferable, although east and west orientations can be acceptable if diffusing glazing is used, or if low-angle sun penetration will not be bothersome in the space. High sidelighting is most appropriate for open plan interior layouts that allow unobstructed daylight penetration. It should be considered in the early schematic design phase.
- **Balance with other daylight needs:** Applied to one wall, this approach creates a decreasing gradient of useable daylight about 2 times the clerestory head height into the space. For spaces of 20–40 feet in width (classrooms, etc.), it can be balanced with a daylighting scheme on the opposite wall to provide even lighting across the entire space. View windows should also be provided. The total glazing area should be apportioned among these needs.

- **Reduced plenum space:** Clerestory sidelighting requires ceiling heights of 9.5 ft or more at the window wall. This extra ceiling height may be accomplished with minimal increase of the floor to floor height by careful integration of the structural system, HVAC ducts and electric lighting in the plenum space. Sloping (or stepping) the ceiling upward at the perimeter (see Figure DL2-1)—essentially reducing the plenum space there—can also yield additional perimeter ceiling height. For ceiling-ducted HVAC systems, this requires routing ducts away from perimeter walls.

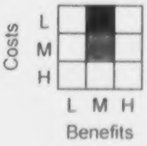


*Sloped ceiling at perimeter increases window head height by reducing plenum space*

- **Natural Ventilation:** High windows can be especially beneficial for natural ventilation, by allowing heated air to escape out near the ceiling. The ideal location for high operable windows is on the leeward side of a building.
- **Integration with HVAC:** High sidelighting glazing impacts HVAC loads by its vulnerability to solar gains during the cooling season and heat loss in the heating season. Good design (appropriate glazing orientation, size, glazing materials, shading and photocontrol of electric lights) can reduce the overall HVAC loads and potentially reduce HVAC system size and first costs.
- Keep duct work away from high windows to avoid blocking daylight.
- **Integration with electric lighting:** High sidelighting creates linear zones of daylight that run parallel to the clerestory windows. Electric lighting should be circuited parallel to this and photocontrolled (or manually controlled) in response to available daylight.

## Costs

Costs for high sidelighting are low to moderate. Windows are standard practice for classrooms. A balance of view and clerestory windows can be provided for each classroom with minimal increase to the overall glazed area. The incremental cost of energy efficient glazing ranges from $0.75 to $2.50 per square foot.



## Benefits

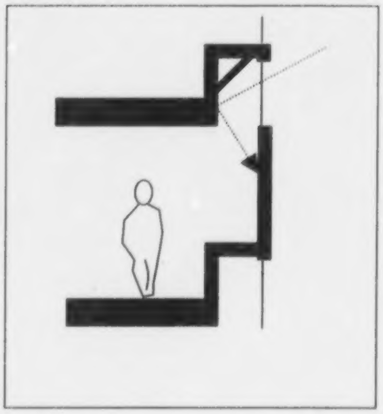
High sidelighting provides a moderate level of benefits. The general energy saving, productivity and visual comfort benefits of daylighting are discussed in the overview section to this chapter. Clerestory sidelighting both saves energy and improves lighting quality. Energy savings come from reduced electric lighting energy use. Lighting quality is improved by a more uniform distribution of daylight across the space.

## Design Tools

Computer simulation programs and scale models as outlined in the overview can be used to demonstrate daylight distribution. If the design includes sloped surfaces, check to ensure the simulation program can accommodate these. Check for daylight levels across the space under both clear sky and overcast sky conditions and check direct sun penetration through the clerestory glazing for the lowest expected sun angles. Even occasional penetration of low sun angles can be extremely bothersome to occupants and may lead to blocking a window.

Energy savings from minimized HVAC loads and control of electric lighting in response to daylight can be calculated with the DOE-2 and Energy 10 programs commercially available.

## Design Details



*Clerestories in multistory buildings can redirect daylight onto the perimeter wall to brighten it.*

- **Ceiling height:** High sidelighting glazing works best in spaces with high ceilings. A minimum perimeter ceiling height of 9.5 ft is recommended. Generally, the higher the ceiling height, the better.
- **Balancing with view windows:** Lower view windows are frequently coupled with high sidelighting schemes, but they don't have to coincide for the whole perimeter. The high glazing should be continuous along the whole area to be daylit. View windows can be selectively spaced beneath these high windows as needed. This balance between high clerestories and view windows can leave lower perimeter wall space available for other uses.
- **Shading devices:** Design high sidelighting clerestories with exterior shading, diffusing glazing, operable blinds or light shelves to eliminate direct sun penetration. Miniblinds positioned between the panes of glass in a double-glazed window accomplish this with minimal maintenance. (A light shelf or louver system may also be used; see Guideline DL3.) Dedicated blinds or shades for the upper clerestory glazing can allow lower view windows to be controlled separately for glare. Blackout shades may need to be provided.
- **Glazing materials:** New glazing materials (prismatic, lensed, holographic, or laser cut acrylic) may be available to redirect daylight to the ceiling from the clerestory. These can deliver daylight deeper in the space but may cause very bright glazed areas and should be tested to see if they produce glare.
- **Orientation:** Clerestories are most effective on south and north orientations. Their use should be carefully evaluated on east and west orientations to assure that low sun angle penetration and direct solar gain into the space is minimized. Shade exterior glazing with an overhang on east, west and south-facing glazing to minimize solar gain or use a selective low-e coating (SHGC less than .45).
- **Visible transmission:** Use high transmission, clear glazing (visible transmission 60% to 90%) on the upper window to admit the maximum daylight to the space. Double clear low-e glazing is recommended in the desert, mountain and Central Valley climates; single clear glass is recommended in coastal climates.
- **Stepped ceiling:** Clerestories may create a comparatively dark area along the wall directly beneath them. An interior stepped ceiling in a multistory building can create a clerestory that reflects daylight back onto the wall to brighten it and deliver reflected daylight to the space.
- **Reflectance:** Paint all surfaces near the clerestories white or off-white to reduce contrast between the brightness of the clerestory and its surrounding wall. The adjacent ceiling should also have a highly reflective (>70%) white or off-white surface to help diffuse a maximum amount of daylight into the space. Use specially designed "high reflectance" ceiling tiles if the budget allows.
- **Teaching surface:** In classrooms, the teaching surface should be perpendicular to the window wall for best illumination. Avoid orientations that will put students' or teachers' faces in silhouette or cause reflected glare on whiteboards or computer screens.

## Operation and Maintenance Issues

For operable louvers, it is best to have preset angles that are seasonally adjusted by maintenance staff so the louvers are not inadvertently closed and forgotten or left at a non-optimal angle.

For shades or blinds that are operated by teachers, ensure that their control mechanisms are accessible, robust and easily repaired.

Clerestory windows should be washed on a regular schedule.

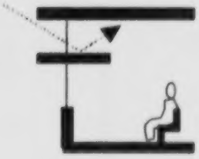
### Commissioning

Set adjustable louvers at their correct seasonal angle to eliminate direct sun penetration.

### Example(s)

### References / Additional Information

# Guideline DL3: High Sidelighting—Clerestory with Light Shelf or Louvers



## Recommendation

Use light shelves or louvers with high clerestory glazing in perimeter walls to improve daylight distribution, block direct sun penetration, and minimize glare in classrooms, offices, libraries, multipurpose rooms, gymnasiums and administrative areas.

## Description

A light shelf is a horizontal panel placed below high clerestory glazing (with a view window generally below it) to bounce daylight deeper into the space. Light distribution is improved as daylight reflects off the top surface of the light shelf or louver onto the ceiling. A series of smaller horizontal louvers (6–24 in. wide) can replace a single large light shelf with a slight sacrifice in performance. The larger the louver, the deeper it will deliver daylight into the space. Light shelves and louvers can be located on the exterior, interior or both. Exterior shelves shade the lower window from solar heat gain and reflect high angle summer sun into the room. Interior shelves reflect lower angle winter sun while blocking the penetration of direct sun and reducing glare from the upper glazing (see Figure DL3-1).

## Applicability

High clerestory windows can be used in most school spaces to provide deep penetration of daylight. They are applicable to all climate regions and should be planned in the schematic design phase.

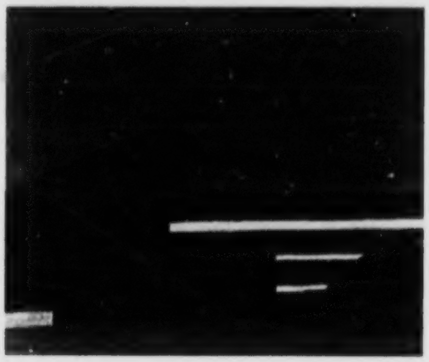
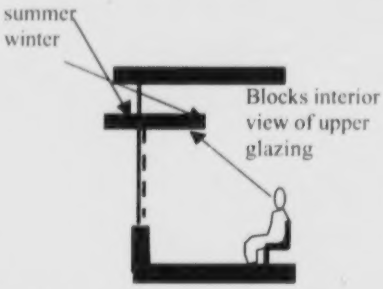


*Photo of Liberty Elementary School with exterior lightshelves to reflect sunlight onto classroom ceilings. Photo courtesy of Liberty elementary, Boise School District, Boise, ID*



*Exterior light shelves shade lower window and reflect summer sun into room. Interior shelves reflect winter sun while reducing glare.*

| Applicable Spaces |  | Climates |  | When to |  |
|---|---|---|---|---|---|
| Classrooms | ■ | South Coast | ■ | Programming | ■ |
| Library | ■ | North Coast | ■ | Schematic | ■ |
| Mulit-Purpose / Cafeteria | ■ | Central Valley | ■ | Design Dev | ▨ |
| Gym | ■ | Mountains | ■ | Contract Docs | ▨ |
| Corridors | ■ | Desert | ■ | Construction | ▨ |
| Administration | ■ |  |  | Commissioning | ☐ |
| Toilets | ☐ |  |  | Operation | ☐ |
| Other | ☐ |  |  |  |  |

## Applicable Codes

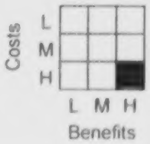
The California energy efficiency code does not require that high side lighting with light shelves be installed. However, the code does specify the minimum performance of fenestration products and it limits window area to a maximum of 40% of the exterior wall area.

## Integrated Design Implications

- **Design Phase:** Clerestories with light shelves require perimeter access to south-facing (+/- 15 degrees) sidelighting and impact many aspects of building massing. They also benefit from open plan interior layouts that allow unobstructed daylight penetration. They should be considered in the early schematic design phase. Calculation of the size and cutoff angles of the light shelf or louver system is critical.
- **Balance with Other Daylight Needs:** Applied to one wall, this approach creates a decreasing gradient of useable daylight about 2.5 times the clerestory head height into the space. For spaces of 20–50 feet in width (such as classrooms), it can be balanced with a daylighting scheme on the opposite wall to provide even lighting across the entire space. Lower view windows are frequently coupled with light shelf schemes, but they don't have to coincide for the whole length of the light shelf. The high glazing with light shelf should be continuous along the whole area to be daylighted. View windows can be selectively spaced beneath the light shelf as needed. This balance between high sidelighting and view windows leaves some lower perimeter wall space available for other uses. Total glazing area should be apportioned among these needs.
- **Integration with Ceiling Plenum:** Clerestories with light shelves require ceiling heights of 9.5 ft or more at the window wall. This extra ceiling height may be accomplished with minimal increase of the floor-to-floor height by careful integration of the structural system, HVAC ducts and electric lighting in the plenum space. Sloping (or stepping) the ceiling upward at the perimeter—essentially reducing the plenum space there—can also yield additional perimeter ceiling height. For ceiling-ducted HVAC systems, this requires routing ducts away from perimeter walls.
- **Integration with HVAC***:* Glazing above a light shelf impacts HVAC loads by its vulnerability to solar gains during the cooling season and heat loss in the heating season. Good design (appropriate glazing orientation, size, performance and shading and photocontrol of electric lights) can reduce the overall HVAC loads and potentially reduce HVAC system size and first costs.
- Light shelves also must be designed so as not to interfere with circulation of air from the HVAC system.
- **Integration with Electric Lighting:** Clerestories with light shelves create linear zones of daylight that run parallel to the clerestory windows. Electric lighting should be circuited parallel to this and photocontrolled (or manually controlled) in response to available daylight. Light shelves and louvers deliver daylight indirectly to the space; they work well when coupled with direct/indirect pendant electric lighting. Sometimes the first row of electric lighting is incorporated into the light shelf itself.
- **Integration with Other Mechanical Systems:** Design light shelves so they don't interfere with the operation of a fire sprinkler system.

## Costs

Clerestories with light shelves or louvers are relatively expensive, but some of the costs may be offset by downsizing cooling systems (if electric lights are automatically switched or dimmed in response to daylight). Energy savings from reduced lighting and cooling energy are adequate to recover the initial investment in about 8 to 12 years.



## Benefits

Clerestories with light shelves or louvers produce a high level of benefits. The general energy saving, productivity and visual comfort benefits of daylighting are discussed in the overview section to this chapter. Clerestories with light shelves or louvers both save energy and improve lighting quality. Energy savings come from reduced solar gains (when an exterior light shelf shades lower glazing) and reduced lighting energy use.

Lighting quality is improved because daylight is delivered deeper in the space, creating a more even distribution of daylight. Interior light shelves and louvers restrict the view of the bright upper glazing, eliminating glare.

## Design Tools

Computer simulation programs and scale models as outlined in the overview can be used to demonstrate daylight distribution. If the design includes sloped surfaces, check to ensure the simulation program can accommodate these. Check for daylight levels across the space under both clear sky and overcast sky conditions and check direct sun penetration through the upper glazing for the lowest expected sun angles.

Most whole building energy simulation programs (like DOE-2 and Energy 10) do not accurately represent the increased daylight distribution from a light shelf or louver system. For more accurate simulations of electric lighting energy savings, the daylight distribution should be simulated with a physical scale model or daylight simulation program and then input to the energy program.

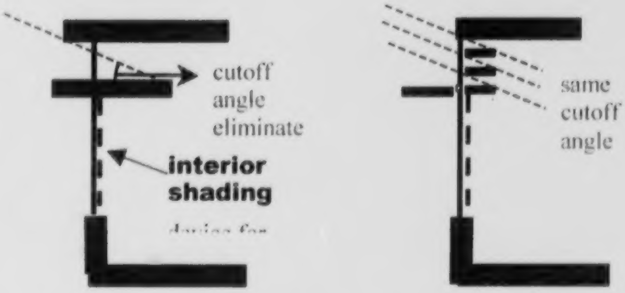


*Figure DL3-1 Set the cutoff angle of light shelves or louvers to eliminated direct sun penetration during normal school hours.*

## Design Details

- **Ceiling height:** Provide a minimum perimeter ceiling height of 9.5 ft (the higher, the better). Position the light shelf at 7 ft or more above the floor. Coordinate shelf position with pendant electric lighting, door headers, shelving, fire sprinklers and other interior features.
- **Orientation:** Light shelves are most effective on south orientations, and occasionally on the north (to reduce glare from the upper glazing). They should be avoided on east and west orientations.
- **Cutoff angle:** Set the cutoff angle of the light shelf or louvers (see Figure DL3-1) to eliminate direct sun penetration during normal school hours. (Use a cutoff angle of 27 degrees for latitudes north of Chico. Use a cutoff angle of 23 degrees for latitudes between Chico and Bakersfield. Use a cutoff angle of 20 degrees for latitudes south of Bakersfield. . Cutoff angle can be increased by 10 degrees if there are operable shades on the upper glazing, and increased by 20 degrees if operable louvers will be seasonally adjusted.
- **Visible transmission:** Use high transmission, clear glazing (visible transmission 60% to 90%) on the upper window to admit the maximum daylight to the space. Double glazing with low-e is recommended in the desert, mountain and Central Valley climates. Single clear glass is acceptable in coastal climates.
- **Reflectance:** The top surface of the light shelf or louvers should be highly reflective (greater than 80% reflectance and with a diffuse, not mirrored, surface). Paint all surfaces near the clerestories white or off-white to reduce contrast between the brightness of the clerestory and its surrounding wall. The adjacent ceiling should also have a highly reflective (>70%) white or off-white surface to help diffuse a maximum amount of daylight into the space. Use specially designed "high reflectance" ceiling tiles if the budget allows.

- **Materials:** Light shelves and louvers may be opaque or translucent and constructed of wood, metal panels, GFRC (glass fiber reinforced concrete), plastic, fabric, or acoustic ceiling materials. Choice of material should include consideration of reflectivity, structural strength, cost, ease of maintenance, and durability. Some curtain wall or window manufacturers can assist in developing details for light shelves and offer add-on products as part of their service. Fabric "shelves" can be suspended from the ceiling at their interior edge.
- **Top surface:** The top surface of a row of lockers or casework that lines a perimeter wall can also be used as a light shelf if its reflectivity and dimensions are appropriate. Slope the top surface so it won't be used for storage.

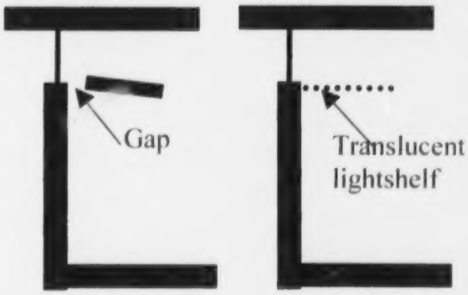


*Figure DL3-2 If opaque light shelves aren't coupled with view windows, consider leaving a gap between the light shelf and the wall to create a wall wash. Translucent shelves provide a soft light under them.*

- **Opaque vs. translucent shelves:** Opaque shelves may create a dark space along the wall directly under them if they're not coupled with a view window. Leave a gap between the light shelf and the wall to create a wall wash or use electric lighting to brighten this wall. Translucent shelves provide a soft light under them but must be carefully evaluated so the direct view of their under side does not create glare. See Figure DL3-2.
- **Dirt accumulation:** To reduce accumulation of dirt, exterior shelves should be sloped at least ¼ in. per foot so that rain can help keep it clean and not pool on the shelf. Also slope interior shelves so they are not used as storage. Fabric construction is another way of preventing this.
- **Accessibility:** Both exterior and interior light shelves can be an "attractive nuisance" in school buildings, inviting students to climb or hang on them. Minimize access to the shelf or use a series of louvers instead.
- **Access for cleaning:** Detail the light shelf or louver system so it is easy to clean the glass above it, both inside and out. Large light shelves may need to be moved away from the window by 6 in. to allow for window cleaning equipment to be inserted from below the shelf.
- **Teaching surface:** In classrooms, the teaching surface should be perpendicular to the window wall for best illumination.

## Operation and Maintenance Issues

The glazing and light shelf/louver system forms a light delivery system that must be kept clean to ensure maximum delivery of daylight to the space. The top surface of the shelf or louvers should be cleaned each time the windows are washed. Make sure light shelves or louvers are detailed correctly to allow easy window cleaning. For operable louvers, it is best to have preset angles that are seasonally adjusted by maintenance staff so the louvers are not inadvertently closed and forgotten or left at a non-optimal angle.

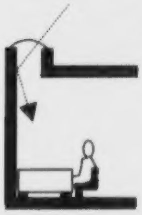
## Commissioning

Unless the light shelf or louvers are moveable, commissioning should not be necessary. Set adjustable louvers at their correct seasonal angle to eliminate direct sun penetration.

## Example(s)

## References / Additional Information

# Guideline DL4: Classroom Daylighting—Wall Wash Top Lighting



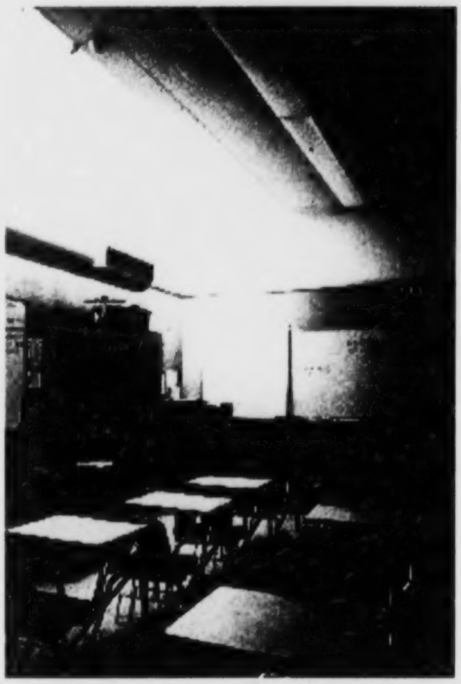


*Figure DL4 1: Skylit wall wash delivers daylight across two-thirds of this classroom. Lisa Heschong, photographer.*

| Applicable Spaces | | Climates | | When to Consider | |
|---|---|---|---|---|---|
| Classrooms | ■ | South Coast | ■ | Programming | ■ |
| Library | ■ | North Coast | ■ | Schematic | ■ |
| Mulit-Purpose / Cafeteria | ■ | Central | ■ | Design Dev. | ■ |
| Gym | ■ | Mountains | ■ | Contract Docs | ▨ |
| Corridors | ■ | Desert | ■ | Construction | ▨ |
| Administration | ■ | | | Commissioning | ☐ |
| Toilets | ▨ | | | Operation | ☐ |
| Other | ▨ | | | | |

### Recommendation

Use wall wash top lighting for interior classroom walls to balance daylight from window walls, brighten interior classrooms and make them seem more spacious.

### Description

Wall wash toplighting provides daylight from above through a linear skylight or monitor to wash an interior wall. The glazing is obscured from direct view by the skylight or monitor well. Daylight is diffused with diffusing glazing, baffles or reflections off of matte reflective light well and interior walls.

### Applicability

A toplighting scheme applies to single-story buildings or the top floor only of a multistory building. Appropriate spaces for wall wash toplighting may include classrooms, libraries, multipurpose spaces, gyms, corridors and administration offices. It is applicable to all climate regions, and must be planned for in schematic design.

### Applicable Codes

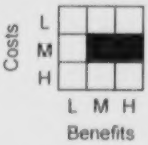
### Integrated Design Implications

- **Balance with other daylight:** Applied to one wall, this approach creates even daylight across about two-thirds of a classroom. It should be balanced with a daylighting scheme on the opposite wall to provide even lighting across the entire classroom. View windows should also be provided. The total glazing area should be apportioned among these needs.
- **Skylights vs. vertical glazing:** The glazing for this wall wash toplighting scheme may be either horizontal or vertical (facing north, east, south or west). See Daylighting Design Considerations in the electronic Appendix for a discussion of the energy performance of sidelighting versus toplighting facing in different orientations for all of the California climate zones. Skylights can offer an advantage of lower construction costs.
- **Integration with HVAC:** Placement of skylights and monitors and their associated light wells must be coordinated with the location of rooftop HVAC equipment and interior duct runs. If it is oriented, glazed, shaded and integrated with electric lighting controls, toplighting should decrease overall seasonal heating and cooling loads on the building. This can reduce the initial size of the HVAC system and annual energy costs.

- **Integration with mechanical ventilation:** Operable rooftop fenestration can be used to naturally ventilate the space. Evaluate thermal stratification of air in the space and prevailing wind conditions to assess the feasibility.
- **Integration with structural system:** Skylights and monitors interrupt the roof diaphragm and structural system. Their size and location may be limited by this and must be coordinated with the structural system to maintain its strength and integrity. See Daylighting Design Considerations in the electronic Appendix for more details.
- **Safety and Security:** Toplighting scenarios on relatively flat roofs have liabilities for both safety and security. Refer to Daylighting Design Considerations in electronic Appendix for more details.

## Costs

Costs for wall wash toplighting are moderate to high, depending on design. Commercial, single glazed skylights are usually the least expensive approach.



## Benefits

Wall wash toplighting provides a moderate to high level of benefits. This approach washes a wall with light, and bounces glare-free daylight into the classroom. It will make the space appear larger and brighter. The uniform light from this approach can easily light the inner two-thirds of a classroom. It is excellent when combined with another wall wash or a sidelighting technique that increases daylight on the opposite side of the room (for example, a perimeter window) to create even, balanced daylight across the whole room.

This approach saves electric lighting energy if the first row or two of lights adjacent to the wall wash are switched off or dimmed in response to the daylight. Savings for controlled fixtures may be 40–80% during daylight hours.

If this scheme is used to provide natural ventilation, it may increase student performance. Natural ventilation has been shown to be correlated with higher student scores on standardized tests and lower overall building energy use (Heschong Mahone Group 1999; Florida Solar Energy Center 1996).

## Design Tools

The computer simulation programs and scale models described in the Overview can be used to demonstrate daylight distribution. If the design includes sloped surfaces, check to ensure the simulation program can handle this.

## Design Details

### General

**Orientation:** Optimize the toplighting design for the climate, orientation and budget. A skylight will perform better in a predominantly overcast sky condition and non-north/south orientations. A well-designed monitor with north- or south-facing glazing will be more expensive, but may perform better than a skylight in sunny climates with high AC loads.

**Diffusion:** Diffuse the daylight before it washes the wall. Eliminate direct sun patches with diffusing glazing, baffles or a deep well. For skylights, use a high performance diffusing material, such as prismatic acrylic, to maximize light transmission while minimizing hot spots. For clear glazed, baffled systems, design fixed baffles to cut off all expected sun angles or provide adjustable baffles.

**Visible transmittance**: Use glazing with the highest visible transmittance (Tvis) to bring in the most daylight relative to the glazed area. For vertical glass, use a low-e coating to minimize heat loss; use a selective low-e coating to minimize solar gain on solar orientations.

**Light wells:** A light well connects the upper aperture with the ceiling plane of the classroom. Light well walls should be highly reflective (>80% reflectance). Diffusely reflecting light wells should be less than 8' deep; mirrored reflecting wells can be used for deeper wells when necessary.

**Surface colors:** The top of the wall that is washed should be light in color (>70% reflectance) so it can reflect daylight into the space. It should not have protrusions that will cast objectionable shadows.

**Balancing daylight:** Combine wall wash toplighting approach with another linear approach on the opposite wall to balance daylight in the space.

**Insulation:** Insulate light well walls to minimize thermal losses and reduce condensation.

**Task and accent lighting:** In addition to ambient lighting, this approach can be used for task lighting on the wall (for example, lighting lockers) or accent lighting (lighting artwork, for example). It is excellent for corridors and other circulation spaces.

**Blackout capability:** The aperture will need blackout capability for most classrooms.

**Integrating with electric light:** Consider an electric lighting wall wash luminaire to illuminate the wall at night, or during heavily overcast conditions. Photoswitch this light in response to daylight levels.

**Safety and security:** Operable mechanisms should prevent any physical entry. A safety/security grating can be placed in the light well under the glazing for this toplighting scheme. (Light control louvers and baffles may also serve this function.) Make sure this grating does not create a shadow pattern on the wall. See Daylighting Design Considerations in the electronic Appendix for more discussion of safety and security issues with toplighting.

**Leakage:** All roof penetrations have leakage liabilities. Use well-tested curb design details and flashing kits provided by the manufacturer. Any operable opening should prevent rain penetration.

#### Monitors

Monitors with glazing oriented north or south (elongated east/west) will exhibit the least variation of daylight levels throughout the day and will be easiest to design for good energy performance. South-facing vertical glazing should have an overhang, or spectrally selective low-e coating (SHGC less than .45) to reduce solar gains during the cooling season combined with a baffles or diffusing glazing to eliminate direct sun. Monitors with glazing oriented east or west are more likely to show variations in light level and quality from morning to afternoon. If the east-west orientation is required, a skylight may perform better than a monitor.

### Operation and Maintenance Issues

- Educate teachers about how wall wash toplighting delivers daylight to the space; discourage them from placing dark colored artwork and posters high on the washed wall.
- Clean glazing on a schedule. Horizontal glazing needs more frequent cleaning in climates with low rainfall.
- The mechanisms for operable louvers and blackout shades should be robust, accessible to the instructor and easily repaired.
- Daily janitorial service should check all operable windows or skylights for closure

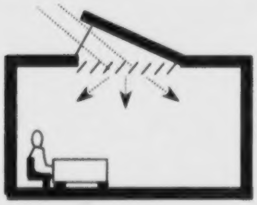
### Commissioning

Check to ascertain that operable louvers and shades are working. Set angles of adjustable louvers to eliminate direct sun penetration.

### Example(s)

## References / Additional Information

# Guideline DL5: Central Toplighting



*Central sawtooth monitor provides even illumination across desktops in this classroom. Photo courtesy: Barbara Erwine*

| Applicable Spaces | |
|---|---|
| Classrooms | ■ |
| Library | ■ |
| Mulit-Purpose / Cafeteria | ■ |
| Gym | ▨ |
| Corridors | ☐ |
| Administration | ■ |
| Toilets | ▨ |
| Other | ☐ |

| Climates | |
|---|---|
| South Coast | ■ |
| North Coast | ■ |
| Central | ■ |
| Mountains | ■ |
| Desert | ■ |

| When to Consider | |
|---|---|
| Programming | ■ |
| Schematic | ■ |
| Design Dev | ■ |
| Contract Docs | ▨ |
| Construction | ▨ |
| Commissioning | ☐ |
| Operation | ☐ |

## Recommendation

Use central toplighting in single-story classrooms to provide high levels of even, balanced daylight across the entire room.

## Description

Central toplighting is accomplished by a central monitor or skylight (or cluster of skylights) that distributes daylight evenly across the room. Daylight is diffused with diffusing glazing or baffles that can be fixed or operable. Daylight levels are highest directly under the aperture and gradually reduce toward the perimeter of the space.

## Applicability

Central toplighting is applicable in single-story or top floor spaces including classrooms, libraries, multipurpose spaces and administrative offices. It is appropriate for all climate regions, and should be considered during the programmatic, schematic and design development phases of a school building project.

## Applicable Codes

## Integrated Design Implications

- **Integration with site plan:** Since this is a toplighting scheme, it applies to single-story buildings or the top floor only of a multistory building. Thus it must be planned for in schematic design.
- **Skylight vs. vertical glazing:** The glazing for a central toplighting scheme may be either horizontal or vertical (facing north, east, south or west). See Daylighting Design Considerations in the on-line Appendix for a discussion of the energy performance of horizontal versus vertical glazing facing in different orientations and an evaluation of the relative HVAC loads.
- **Balance with other daylight:** This scheme may be combined with view windows in perimeter walls. Since most of the ambient daylight is provided by the toplighting aperture, smaller windows can be judiciously spaced in exterior walls to optimize views and valuable wall space can be relinquished for other needs. The total glazing area should be apportioned among these needs.
- **Integration with HVAC :** Placement of skylights and monitors and their associated light wells must be coordinated with the location of rooftop HVAC equipment and interior ducts.
- **Integration with structural system:** Skylights and monitors interrupt the roof diaphragm and structural system. Their size and location may be limited by this and must be coordinated with the

structural system to maintain its strength and integrity. See Daylighting Design Considerations in the on-line Appendix for more details about toplighting design.

- **Integration with electric lighting:** Central daylighting schemes often fail to provide bright illumination on interior walls. Electric lighting wall wash fixtures may be needed to supplement the daylight.
- **Integration with mechanical ventilation:** If the toplighting fenestration is operable, it can be used to naturally ventilate the space. Evaluate thermal stratification of air in the space and prevailing wind conditions to assess the feasibility.
- **Safety and security:** Toplighting scenarios on relatively flat roofs have both safety and security issues. The Daylighting Design Considerations section of Appendix A discusses these concerns in more detail.

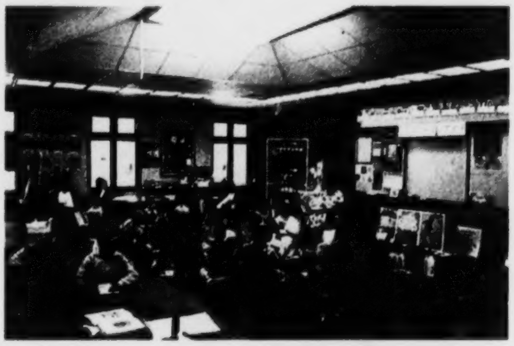
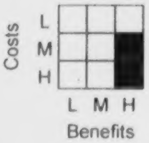


*Figure DL5-1 Classroom with central skylight and splayed light well walls. Photo courtesy PJHM Architects*

## Costs

Costs for central toplighting are medium to high, depending on design. Commercial, double-glazed skylights or a diffusing, double wall panel system with a sheetrocked well will be the least expensive. Site-built monitors with vertical or sloped glazing will cost more.



## Benefits

Central toplighting provides a high level of benefits. With good diffusion, this approach creates even, balanced daylight across the classroom which has been correlated with higher standardized test scores. (But note also that uncontrolled direct sun toplighting in classrooms has been associated with lower standardized test scores. See the Overview to this chapter for details.)

This approach saves electric lighting energy if the electric lights are switched off or dimmed in response to the daylight. Savings may be 40–80% during daylight hours.

Operable louvers can provide variable amounts of daylight for different classroom activities.

Operable skylights or monitor glazing can provide the top outlet for a natural ventilation scheme that draws fresh air in through a lower aperture. Natural ventilation may improve student performance. It has been shown to be positively correlated with higher student scores on standardized tests and lower overall building energy use (Heschong Mahone Group 1999; Florida Solar Energy Center 1997).

## Design Tools

The computer simulation programs and scale models described in the Overview can be used to demonstrate daylight distribution and resultant daylight levels. If the design includes sloped surfaces, check that the simulation program can handle this. The SkyCalc program can be used to optimize the size and energy performance of a central skylight scheme.

## Design Details

### General

**Visible transmittance:** Use high visible transmission glazing materials (greater than 60%) to maximize daylight while minimizing the size of the glazed area with its relatively low U-factor. Single glazing is adequate for most California climates. Double glazing is recommended for mountain regions. Alternatively, larger areas of low-transmission glazing with high insulation levels, such as insulated fiberglass panels, may be used successfully. The balance between visible transmittance and insulation levels is best studied with an hourly climate simulation software tool.

**Orientation:** Optimize the toplighting design for the climate and budget. A skylight will perform better in a predominantly overcast sky condition or non-optimum orientation. A well designed, north or south facing monitor will be more expensive, but may perform better than a skylight for sunny climates with high air-conditioning loads.

**Reflective materials:** A light well connects the upper aperture with the ceiling plane of the classroom. Light well walls should be highly reflective (>80% reflectance). Bright white, flat paint works best. Diffusely reflecting light wells should be less than 8 ft deep; specular reflecting wells can be used for deeper wells when necessary.

**Diffusion:** Diffuse the daylight with diffusing glazing or baffles. Design baffles to cut off all expected sun angles or be adjustable. Avoid placing diffusing glazing within the normal field of view, as it will cause excessive glare.

**Splayed light wells:** Splay light well walls to spread the daylight more effectively in the space and reduce glare. A 45 to 60 degree angle works best.

**Insulation:** Insulate light well walls to an R-value at least equivalent to the code requirement for wall insulation to minimize thermal losses and reduce condensation.

**Blackout capability:** Add blackout capability as needed and louvers to modulate the daylight levels.

**Integration with electric lighting:** If the light well is visible (not obscured by baffles), provide some electric light so it does not become a "dark hole" at night. Pendant uplight fixtures work well. Photoswitch these lights in response to daylight levels. See the Electric Lighting and Controls chapter for information about control of electric lights in response to available daylight.

**Safety and security:** A safety/security grating can be placed in the light well under the glazing for this toplighting scheme. (Light control louvers and baffles can also serve this function.) Make sure this grating does not create a shadow pattern on the wall. See Daylighting Design Considerations in the on-line Appendix for more information about safety and security issues with toplighting.

**Leakage:** All roof penetrations have leakage liabilities. Use well-tested curb design details and flashing kits provided by the manufacturer.

**Reflectors:** A reflecting device may be placed below the light well to redirect daylight onto the ceiling or walls of the space. This ceiling/wall wash will make the space appear larger and brighter, even though horizontal footcandles measured at desk height may be reduced. The reflector may consist of flat or curved mirrored or matte reflective surfaces. It may also be partially translucent (fabric, plastic or perforated metal). This device will require extra floor to ceiling height and should be studied with a physical scale model to evaluate daylight distribution.

### Skylights

Use a glazed area of about 3–12% of the floor area. Use the lower end of this range for spaces with high air-conditioning or heating loads, and the higher end for temperate climates with more overcast.

### Monitors

A sawtooth monitor with glazing oriented north will exhibit the least variation of daylight levels throughout the day and will have better energy performance than east or west glazing. South facing vertical glazing should have an overhang or spectrally selective low-e (SHGC less than .45) to reduce solar gains during the cooling season. Avoid sawtooth monitors with glazing oriented east or west; they will show large variations in light level and quality from morning to afternoon, and will have poor thermal performance.

## Operation and Maintenance

- Clean glazing on a regular schedule. Horizontal glazing needs more frequent cleaning in climates with low rainfall.
- Mechanisms for operable louvers and blackout shades should be robust, accessible to the teacher, and easily repaired.

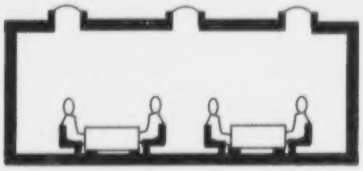
## Commissioning

Check that operable louvers and shades are working. Set angles of adjustable louvers to eliminate direct sun penetration.

## Example(s)

## References / Additional Information

# Guideline DL6: Patterned Toplighting



**Recommendation**

Use patterned toplighting in interior spaces that need even, low glare illumination across a large area.

**Description**

Patterned toplighting provides daylight through a two-dimensional grid of skylights or rows of linear monitors (sawtooth or square). It provides even, glare-free daylight across large areas. Spacing of the pattern is largely a function of the ceiling height.

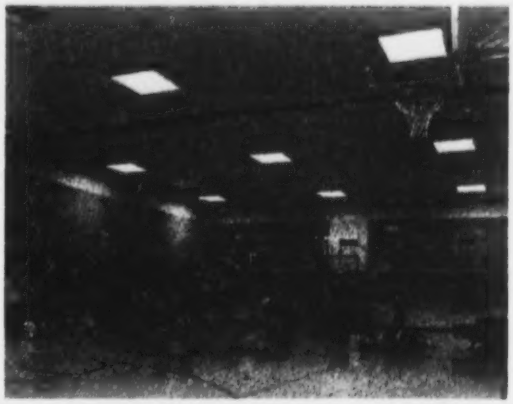


Figure DL6-1: *Grid of skylights in Peoria Gymnasium provide even illumination across the space. Photo courtesy Natural Lighting Co., Inc.*

| Applicable Spaces | | Climates | | When to Consider | |
|---|---|---|---|---|---|
| Classrooms | ■ | South Coast | ■ | Programming | ■ |
| Library | ■ | North Coast | ■ | Schematic | ■ |
| Mulit-Purpose / Cafeteria | ■ | Central | ■ | Design Dev | ■ |
| Gym | ■ | Mountains | ■ | Contract Docs | ▨ |
| Corridors | ☐ | Desert | ■ | Construction | ▨ |
| Administration | ■ | | | Commissioning | ☐ |
| Toilets | ▨ | | | Operation | ☐ |
| Other | ☐ | | | | |

**Applicability**

This daylighting pattern is useful for any large area that needs even daylight levels. It is especially good for gymnasium, library and multipurpose or cafeteria spaces. For gymnasium ball courts, add baffles or high light well cutoff angles to minimize direct views of bright glazing surfaces during ball games (See Design Details below). Patterned toplighting is appropriate for all climate regions, and should be considered during the programmatic, schematic and design development phases.

**Applicable Codes**

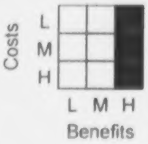
**Integrated Design Implications**

- **Integration with site plan:** Since this is a toplighting scheme, it applies to single-story buildings or the top floor only of a multistory building. Thus it must be planned for in schematic design.
- **Skylight vs. vertical glazing:** The glazing for these patterned toplighting schemes may be either horizontal or vertical (preferably facing north or south). See Daylighting Design Considerations in the on-line Appendix for a discussion of the energy performance of horizontal versus vertical glazing facing in different orientations and an evaluation of the relative HVAC loads.
- **Balance with other daylight:** This scheme may be combined with view windows in perimeter walls. Since most of the ambient daylight is provided by the toplighting aperture, smaller windows can be judiciously spaced in exterior walls to optimize views, and valuable wall space can be relinquished for other needs. The total glazing area should be apportioned among these needs.
- **Integration with HVAC:** Placement of skylights and monitors and their associated light wells must be coordinated with the location of rooftop HVAC equipment and interior duct runs.

- **Integration with mechanical ventilation:** If the toplighting fenestration is operable, it could be used to naturally ventilate the space. Evaluate thermal stratification of air in the space and prevailing wind conditions to assess the feasibility.
- **Integration with structural system:** Skylights and monitors interrupt the roof diaphragm and structural system. Their size and location may be limited by this and must be coordinated with the structural system to maintain its strength and integrity. See Daylighting Design Considerations in the on-line Appendix for more information about integrating toplighting with structural systems.
- **Safety and security:** Toplighting scenarios on relatively flat roofs have both safety and security issues. Check the Daylighting Design Considerations in the on-line Appendix for further discussion of these.

## Costs

Costs for patterned toplighting range from low to high, depending on design. A grid of skylights with unfinished wells will be the least expensive; monitors with reflecting devices will be much more expensive. Costs include the expense of the skylight or monitor device, rooftop installation, curbs and waterproofing, interior well construction and finish, and electric lighting controls to switch or dim in response to daylight.



## Benefits

Patterned toplighting provides a high level of benefits. This approach creates even, balanced, low-glare daylight across the space. This approach saves electric lighting energy if the electric lights are switched off or dimmed in response to the daylight. Savings may be 40–80% during daylight hours.

Operable louvers can provide variable amounts of daylight for different activities. Operable skylights or monitor glazing can provide the top outlet for a natural ventilation scheme that draws fresh air in through a lower aperture. Natural ventilation may improve student performance. It has been shown to be positively correlated with higher student scores on standardized tests and lower overall building energy use (Heschong Mahone Group 1999; Florida Solar Energy Center 1997).

## Design Tools

The computer simulation programs and scale models described in the Overview can be used to demonstrate daylight distribution and resultant daylight levels. If the design includes sloped surfaces, check to ensure the simulation program can handle this. The SkyCalc program can be used to optimize the size of skylight schemes.

## Design Details

### General

- Optimize for climate and budget: Optimize the toplighting design for the climate and budget. A grid of skylights will perform better in a predominantly overcast sky condition. A series of well designed monitors will be more expensive, but will perform better than a skylight for sunny climates with high air-conditioning loads.
- Visible transmittance: Use high visible transmission glazing materials (greater than 60%) to maximize daylight while minimizing the size of the glazed area with its relatively low U-factor. Single glazing is adequate for most California climates. Double glazing is recommended for mountain regions.
- Diffusion: Diffuse the daylight with diffusing glazing or baffles. Design baffles to cut off all expected sun angles or be adjustable. Avoid placing vertical diffusing glazing within the normal field of view.
- Splayed light wells: For deeper, narrow light wells, splay the light well walls to spread the daylight more effectively in the space and reduce glare. A 45 to 60 degree angle works best.

- Reflectance: A light well connects the upper aperture with the ceiling plane of the classroom. Light well walls should be highly reflective (>80% reflectance). Bright white, flat paint works best. Diffusely reflecting light wells should be a maximum of 6–8 ft deep; specular reflecting wells can be used for deeper wells when necessary.
- Insulation: Insulate light well walls to minimize thermal losses and reduce condensation. Use an R-value at least equivalent to the code requirement for wall insulation.
- Blackout capability: Add blackout capability as needed and louvers to modulate the daylight levels.
- Safety and security: A safety/security grating can be placed in light wells under the glazing for this toplighting scheme. (Light control louvers and baffles can also serve this function.)
- Leakage: All roof penetrations have leakage liabilities. Use well-tested curb design details and flashing kits provided by the manufacturer.

### Skylight Grid

As a rough rule of thumb, skylights should be spaced about 1.5 times the floor to ceiling height (H in Figure DL6-2). Their glazing should be about 3–12% of the floor area to be lighted. (Use SkyCalc to optimize the design.)

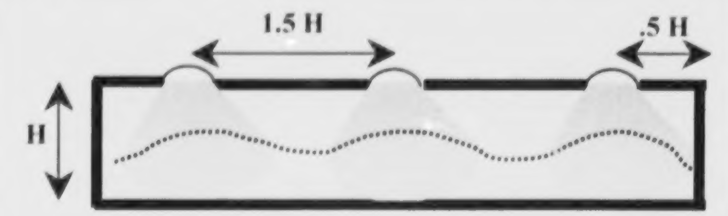


*Figure DL6-2 Skylight grid spacing.*

### Series of Monitors

Sawtooth monitors with glazing oriented north will exhibit the least variation of daylight levels throughout the day and will have better energy performance than east or west glazing. South-facing vertical glazing should be smaller and should have an overhang or spectrally selective low-e coating (SHGC less than .45) to reduce solar gains during the cooling season. Avoid sawtooth monitors with glazing oriented east or west; they will show large variations in light level and quality from morning to afternoon, and poor energy performance.

## Operation and Maintenance

- Clean glazing on a regular schedule. Horizontal glazing needs more frequent cleaning in climates with low rainfall.
- Mechanisms for operable louvers and blackout shades should be robust, accessible to the instructor, and easily repaired.

## Commissioning

Check that operable louvers and shades are working. Set angles of adjustable louvers to eliminate direct sun penetration.

## Example(s)

## References / Additional Information

# Guideline DL7: Linear Toplighting

### Recommendation

Use linear toplighting as a single downlighting element in a long, linear space (such as a corridor) to direct movement or establish a visual orientation. Use it on two sides of a space to define separate functions or activities, to define edges in a larger space, and/or to downlight the space from two directions.

### Description

Linear toplighting is a downlighting scheme that provides a line of high intensity daylight directly under it, which diminishes as you move perpendicularly away from it. It establishes a strong longitudinal orientation in the space and is best coupled with a corresponding circulation pattern or linear visual cue. Used bilaterally (from two sides), it can frame a larger space.

### Applicability

This daylighting pattern is useful for enclosed hallways, linear walkways within a larger space or used bilaterally to frame centrally focused areas like gymnasiums, libraries and multipurpose areas. Linear toplighting may also be used in covered exterior walkways to minimize their shadow, especially in covered walkways adjacent to school rooms with sidelighting.

### Applicable Codes

The California energy code specifies the minimum performance of fenestration products and it limits window area to a maximum of 5% of the exterior roof area.

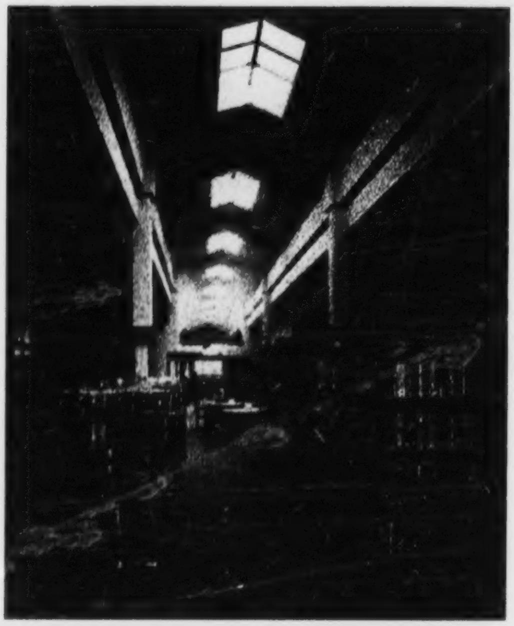


*Figure DL7- 1: Linear skylight in this library spreads daylight to adjacent spaces and organizes the circulation*

| Applicable Spaces | | Climates | | When to Consider | |
|---|---|---|---|---|---|
| Classrooms | ☐ | South Coast | ■ | Programming | ■ |
| Library | ■ | North Coast | ■ | Schematic | ■ |
| Mulit-Purpose / Cafeteria | ▨ | Central | ■ | Design Dev | ■ |
| Gym | ■ | Mountains | ■ | Contract Docs | ▨ |
| Corridors | ■ | Desert | ■ | Construction | ▨ |
| Administration | ☐ | | | Commissioning | ☐ |
| Toilets | ☐ | | | Operation | ☐ |
| Other | ☐ | | | | |

### Integrated Design Implications

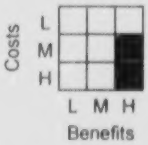
- **Design Phase:** Since this is a toplighting scheme, it applies to single-story buildings or the top floor only of a multistory building. It must be integrated with the site plan and building massing and should be planned for in the schematic design phase.
- **Balance with other daylight:** Since overall glazing area is limited, the amount of glazing in a linear toplighting scheme must be balanced with the need for view windows and other apertures in the space.
- **Integration with electric lighting:** Electric lighting should be aligned with the toplighting without blocking it and causing shadows on the floor.
- **Integration with structural system:** Skylights and monitors interrupt the roof diaphragm and structural system. Their size and location may be limited by this and must be coordinated with the

structural system to maintain its strength and integrity. See Daylighting Design Considerations in the on-line Appendix for more about integrating toplighting with structural systems.

- **Integration with HVAC:** Placement of the linear toplight and its associated light well must be coordinated with the location of rooftop HVAC equipment and interior duct runs. Interruptions in the linear run of this toplight may be required to accommodate these other needs. These interruptions should be sequenced in a regular manner so as not to create a random pattern of light and dark.
- **Integration with mechanical ventilation:** If the toplighting fenestration is operable, it could be used to naturally ventilate the space. Evaluate thermal stratification of air in the space and prevailing wind conditions to assess the feasibility.
- **Safety and security:** Toplighting scenarios on relatively flat roofs have both safety and security issues. Check Daylighting Design Considerations in the on-line Appendix for further discussion.

## Costs

Costs for linear toplighting range from moderate to high, depending on design. A linear row of skylights will be the least expensive; monitors with reflecting devices will be more expensive. Costs include the expense of the skylight or monitor device, rooftop installation, curbs and waterproofing, interior well construction and finish, and electric lighting controls to switch or dim in response to daylight.



## Benefits

Linear toplighting provides a high level of benefits. This approach creates bright, welcoming corridors that link important functions in the building. It can provide a strong visual cue for circulation that guarantees daytime egress lighting independent of electric power. In a bilateral scenario, it can provide balanced daylighting which graduates from high at the perimeter to moderate between the two linear toplights.

This approach saves electric lighting energy if the electric lights are switched off or dimmed in response to the daylight. Savings may be 40–80% during daylight hours.

Operable skylights or monitor glazing can provide the top outlet for a natural ventilation scheme that draws fresh air in through a lower aperture. Natural ventilation may improve student performance. It has been shown to be positively correlated with higher student scores on standardized tests and lower overall building energy use (Heschong Mahone Group 1999; Florida Solar Energy Center 1997).

## Design Tools

The computer simulation programs and scale models described in the Overview can be used to demonstrate daylight distribution and resultant daylight levels. If the design includes sloped surfaces, check to ensure the simulation program can handle this. The SkyCalc program can be used to optimize the size of a skylight scheme.

## Design Details

- **Visible transmittance:** Use high visible transmission glazing materials (greater than 60%) to maximize daylight while minimizing the size of the glazed area with its relatively low U-factor. Single glazing is adequate for most California climates. Double glazing is recommended for mountain regions. Alternatively, larger areas of low-transmission glazing with high insulation levels, such as insulated fiberglass panels, may be used successfully. The balance between visible transmittance and insulation levels is best studied with an hourly climate simulation software tool.
- **Glazing area vs. floor area:** Use a glazed area of about 3–12% of the floor area. Use the lower end of this range for spaces with high air conditioning or heating loads, and the higher end for temperate climates with more overcast

- **Circulation:** When applicable, coordinate linear toplighting with major circulation areas in the school. You may increase light levels at major intersections and hallway ends to draw students in that direction.
- **Diffusion:** Either diffuse daylight or direct sun may be used in circulation and transition areas. Daylight diffused with translucent glazing or baffles will spread the daylight evenly in the space, making the most effective use of the light. Occasional patches of direct sun can create a vibrant splash of light to emphasize major intersections and circulation spines. Some designs have successfully combined patterns of diffusing glazing with smaller areas of transparent glazing to animate a circulation space.
- **Shared daylighting:** Consider sharing diffuse corridor daylight with adjacent spaces by glazing the upper portion of the wall. Avoid this in areas where acoustic separation is important. In multistory buildings, consider sharing daylight from the top floor corridor with the lower floor by periodically cutting light wells to the lower level.
- **Splayed light wells:** For diffusing skylights with deeper, narrow light wells, splay the light well walls to spread the daylight more effectively in the space and reduce glare. A 45 to 60 degree angle works best.
- **Insulation:** Insulate light well walls to an R-value at least equivalent to the code requirement for wall insulation to minimize thermal losses and reduce condensation.
- **Safety and security:** A safety/security grating can be placed in the light well under the glazing for this toplighting scheme. (Light control louvers and baffles can also serve this function.) Make sure this grating does not create a shadow pattern on the wall.
- **Leakage:** All roof penetrations have leakage liabilities. Use well-tested curb design details and flashing kits provided by the manufacturer.

### Operation and Maintenance

Clean glazing on a schedule. Horizontal glazing (and clear glazing) needs more frequent cleaning in climates with low rainfall.

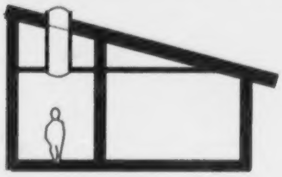
### Commissioning

Check that operable louvers and shades are working. Set angles of adjustable louvers to eliminate direct sun penetration.

### Example(s)

### References / Additional Information

# Guideline DL8: Tubular Skylights



## Recommendation

Use tubular skylights for toplighting in areas with relatively deep roof cavities and for low cost retrofits to existing spaces.

## Description

Tubular skylights are small clear-domed skylights with mirrored reflective ducts connecting them to the ceiling plane of the space. They have an interior diffuser at the ceiling plane to spread daylight in the space. They may have electric lighting within the duct or diffuser that is switched or dimmed in response to the available daylight. Since they depend on multiple reflections to deliver daylight to the space, they perform better under direct sun than overcast sky conditions.

## Applicability

Tubular skylights are especially good for small spaces, such as toilet rooms, locker rooms, kitchens, interior corridors, enclosed staff work areas and other interior spaces that are sporadically occupied and would benefit from a low cost toplighting solution. They are also good for retrofit into any existing school space that needs extra daylight or needs to balance an existing asymmetric daylight distribution.

These units will work significantly better in clear sky climates than in overcast climates. As the duct gets longer, less daylight is delivered; so they are limited to spaces with roof cavities of 8 ft or less.

## Applicable Codes Integrated Design Implications

- **Integration with site plan:** Since this is a toplighting scheme, it applies to single-story buildings or the top floor only of a multistory building. Thus it must be planned for in schematic design.
- **Balance with other daylight:** This scheme may be combined with view windows in perimeter

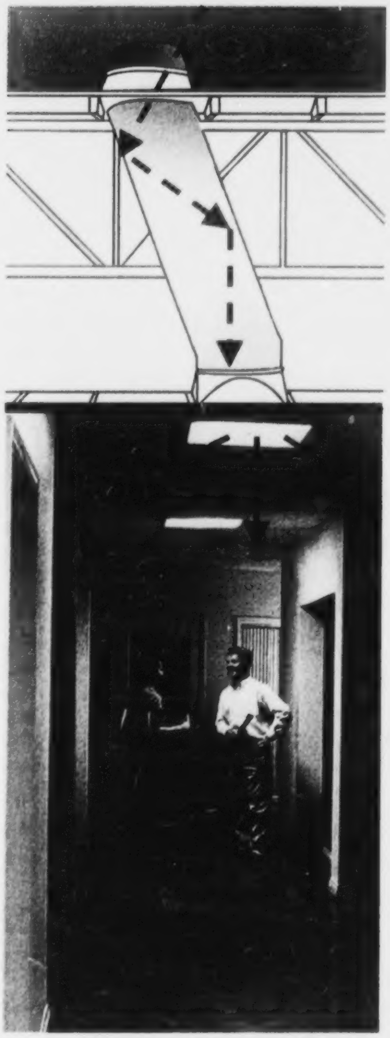


*Figure DL8-1 Tubular skylight. Photo courtesy Solatube, Inc.*

| Applicable Spaces | | Climates | | When to Consider | |
|---|---|---|---|---|---|
| Classrooms | ▨ | South Coast | ■ | Programming | ■ |
| Library | ▨ | North Coast | ■ | Schematic | ■ |
| Mulit-Purpose / Cafeteria | ▨ | Central | ■ | Design Dev | ■ |
| Gym | ▨ | Mountains | ■ | Contract Docs | ▨ |
| Corridors | ■ | Desert | ■ | Construction | ▨ |
| Administration | ▨ | | | Commissioning | ☐ |
| Toilets | ■ | | | Operation | ☐ |
| Other | ■ | | | | |

walls. Since most of the ambient daylight is provided by the toplighting aperture, smaller windows can be judiciously spaced in exterior walls to optimize views and valuable wall space can be relinquished for other needs. The total glazing area should be apportioned among these needs.

- **Integration with HVAC:** Placement of tubular skylights must be coordinated with the location of rooftop HVAC equipment and interior duct runs. Although (within reason) the reflective ducts can jog to avoid barriers in the ceiling plenum space, efficiency of daylight delivery is reduced with each change in direction.
- **Integration with structural system:** Skylights interrupt the roof diaphragm and structural system. Their size and location may be limited by this and must be coordinated with the structural system to maintain its strength and integrity. The small diameter of these units reduces their impact on the structural system relative to larger framed skylights. See Daylighting Design Considerations in Appendix __ for more on integrating toplighting with structural systems.
- **Integration with electric lighting:** Some tubular skylights come equipped with compact fluorescent (or incandescent) electric lights within the duct or ceiling plane diffuser that can be switched or dimmed in response to daylight. Ascertain that any included electric light not block the daylight delivered through the device.
- **Safety and security:** Unless these skylights are larger than 16 in. square, they should not pose a safety or security liability.

## Costs

Costs for tubular skylights are low. An 8 in. tubular skylight can supply daylight to an area of about 100 ft². A 13 in. tubular skylight can serve daylight to an area of about 150 ft².

| Costs | L | M | H |
|---|---|---|---|
| L |  | ■ |  |
| M |  |  |  |
| H |  |  |  |

Benefits

## Benefits

Tubular skylights provide a moderate level of benefits. This approach provides daylight "fixtures" that deliver daylight through a ceiling plenum to an interior space. Arranged in a grid, they can provide even, balanced daylight across the space, though daylight levels will fluctuate widely between direct sun and overcast sky conditions. Daylight in classrooms has been correlated with higher standardized test scores (see the Overview of this chapter for details.)

This approach saves electric lighting energy if the electric lights are switched off or dimmed in response to the daylight. Savings may be 20–60% during daylight hours.

## Design Tools

The specular reflective tube makes it difficult to simulate the performance of these skylights with physical scale models and computer tools. Local case studies, test installations and estimating tools from the manufacturers are the best tools for evaluating performance. Designers should take note that many manufacturers of tubular skylights have made exaggerated claims about both daylight delivery and R-value of their products.

Energy performance of these skylights are also handicapped by the lack of U-factor and Solar Heat Gain Coefficient data. As this information becomes available, hourly building energy evaluation programs like DOE-2 and Energy 10 can be used to evaluate the energy impacts.

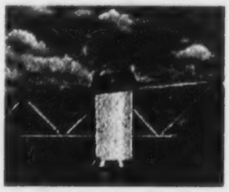


*Figure DL8-2 Cross section of tubular skylight. Courtesy of Solatube, Inc.*

## Design Details

- Length and bends: Minimize the overall length and minimize bends in the reflective duct running from the skylight to the ceiling plane.

- Reflective ducts: Use a product with a highly reflective cylindrical duct. (Don't use a corrugated duct; the corrugations trap light).
- **Half dome vs. full dome:** In predominantly sunny climates, use a tubular skylight with a south-facing, reflective half-dome under the skylight "bubble" to increase the reflection of low angle winter sun into the skylight (see Figure DL8-3). In predominantly overcast climates, use a full clear dome.

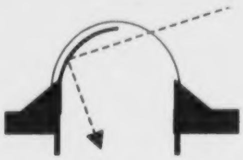


*Figure DL8-3 Section of Reflective Half-Dome*

- **Diffusers:** Some products have a flat bottom diffuser that fits into a standard 2 ft x 2 ft or 2 ft x 4 ft dropped ceiling grid. These may incorporate the electric lighting in them or may alternate in a grid with recessed fluorescent electric lighting fixtures.
- **Insulation:** For ducts installed in uninsulated ceiling or attic spaces, insulate the duct to an R level at least equivalent to the code requirement for air ducts to minimize thermal losses and reduce condensation.
- **Integration with electric lighting:** Consider a system that incorporates a fluorescent (not incandescent) light in the duct to minimize ceiling luminaires. Make sure the electric lamp does not block transmission of daylight. If possible, photoswitch this light in response to daylight.
- **Leakage:** All roof penetrations have leakage liabilities. Use well-tested curb design details and flashing kits provided by the manufacturer.

## Operation and Maintenance

Clean glazing on a schedule. Horizontal glazing needs more frequent cleaning in climates with low rainfall.

## Commissioning

## Example(s)

## References / Additional Information

*Tubular skylights in interior administrative office provide high lighting levels even when electric lights are off. Skylight diffuser panel fits into a standard suspended ceiling system. Photo courtesy of Solatube.*

# BUILDING ENCLOSURE AND INSULATION

The design of the school building enclosure—or envelope—entails many considerations. The materials—both indoors and out—must be durable, resistant to vandalism, easy to clean and inexpensive. They must be strong enough to meet seismic codes and yet appear inviting. Add energy efficiency and sustainability to this list and the job of the design team is even more complex.

This chapter provides technical guidelines for the school building enclosure, including:

Wall Insulation (Guideline IN1)

Roof Insulation (Guideline IN2)

Cool Roofs (Guideline IN3)

Radiant Barriers (Guideline IN4)

Reduce Infiltration (Guideline IN5 )

Fenestration (windows and skylights) is addressed in the chapter on Daylighting and Fenestration Design.

The construction of the building enclosure, especially its color, levels of insulation and thermal mass, has a significant effect on energy efficiency. The building enclosure also affects acoustic comfort as it can attenuate site and traffic noise. The selection of materials for the construction of the building enclosure affects school resource efficiency, including transport energy, the volume and type of raw materials that must be extracted from the earth, the energy required for manufacturing, and packaging. Building shell construction also affects thermal comfort. Even when heating and cooling systems are large enough to make up for poorly insulated components, the building's surface temperature may be cold or hot (depending on season) and this affects the radiant temperature of the space.

## Overview

### Heat Transfer through the Building Enclosure

Heat transfer through envelope components is quite complex and dynamic. The direction and magnitude of heat flow is affected by solar gains from the sun, outdoor temperature and indoor temperature. Building envelope components have three important characteristics that affect their performance: their U-factor or thermal resistance (R-value); their thermal mass or ability to store heat, measured as heat capacity (HC); and their exterior surface condition (for example, are they light in color to reflect the sun or dark to absorb solar heat?). These concepts are explained in greater detail below. Also discussed below is the use of radiant barriers to reduce heat transfer in certain situations.

### U-factor

The U-factor is the rate of steady-state heat flow. It is the amount of heat in Btu (British thermal units) that flows each hour through one square foot of surface area when there is a one-degree temperature difference between the inside air and outside air. Heat flow can be in either direction, as heat will flow from the warmer side to the cooler side. Insulation and most other building materials affect heat flow equally in both directions, but some construction elements such as radiant barriers may reduce heat flow entering the building, but have little impact on heat leaving the building.

Steady-state heat flow assumes that temperatures on both sides of the building envelope element (while different) are held constant for a sufficient period so that heat leaving one side of the assembly is equal to heat entering the opposite side. The concept of steady-state heat flow is a simplification, because in the real world, temperatures change constantly. However, U-factor can predict average heat flow rates over time and is commonly used to explain the thermal performance of construction assemblies. Because they are easy to understand and use, the terms for steady-state heat flow (R-values and U-factors) are part of the basic vocabulary of building energy performance.

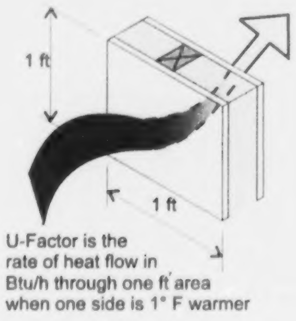

1 ft
1 ft
U-Factor is the rate of heat flow in Btu/h through one ft² area when one side is 1° F warmer

*Figure 12 – Concept of U-factor*

Each layer of a building assembly, such as the sheathing and the insulation, has its own conductance, or rate of heat transfer. The conductance for an individual layer is similar to the U-factor, and it has the same units. When there are multiple elements in a layer, such as wood studs and cavity insulation, the calculations must adjust for the different heat flow rates.

With metal framing, thermal bridges have a significant impact on the performance of the overall assembly, sometimes reducing the insulation effectiveness to less than half. The U-factor accounts for thermal bridges and the conductance of every element of the construction assembly, including the air film conductances on the interior and exterior surfaces. The air film conductances quantify the rate at which heat is transferred between the surface of the construction assembly and the surrounding environment. This conductance depends on the orientation and roughness of the surface and the wind speed across the surface.

For light frame walls, U-factors provide an adequate description of heat transfer. For heavy concrete and masonry walls, however, this is only true under constant temperature conditions. The dynamic heat storage properties of concrete and masonry alter the thermal behavior of the wall, and the U-factor becomes less accurate as a predictor of heat flow (see discussion of heat capacity below).

### R-values

R-values are also used to describe steady-state heat flow but in a slightly different way. The R-value is the thermal resistance to heat flow. A larger R-value has greater thermal resistance, or more insulating ability, than a smaller R-value. The opposite is true with U-factors, that is, the lower the better.

R-values are widely recognized in the building industry and are used to describe insulation effectiveness. The insulation R-value does not describe the overall performance of the complete assembly, however. It only describes the thermal resistance of the insulation material. The performance of the entire wall assembly can be significantly lower when metal framing or other elements penetrate the insulation.

Most construction assemblies include more than one material in the same layer. For example, a wood stud wall includes cavity areas where the insulation is located and other areas where there are solid wood framing members. The wood areas have a lower R-value and conduct heat more readily than the insulated areas. Framing members must be considered when calculating the U-factor of a wall, roof, or floor assembly. See the Design and Analysis Tools section below for more details.

### Thermal Mass

Thermal mass is another important characteristic that affects the thermal performance of construction assemblies. Heavy walls, roofs and floors have more thermal mass than light ones do. Thermal mass both delays and dampens heat transfer (see Figure 13). The time lag between peak outdoor temperature and interior heat transfer is between 4 and 12 hours depending on the heat capacity of the construction and other characteristics. For buildings like schools that are typically not heated or cooled at night, delaying heat transfer can be just as effective as reducing it.

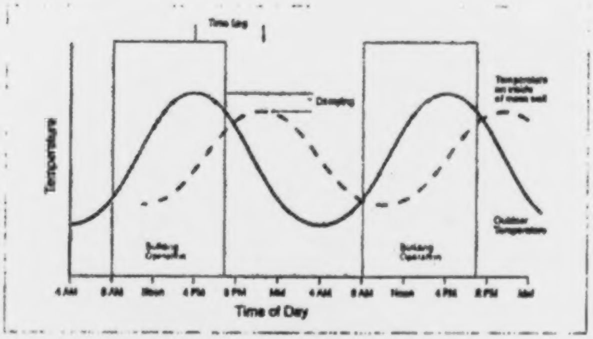


*Figure 13 – Temporature Swing*

Thermal mass that is exposed to interior air has other benefits as well. If the mass is allowed to cool at night, it will absorb heat during the morning and reduce the cooling load. If the interior thermal mass is exposed to sunlight, it will warm during the day and release the heat at night. Thermal mass used this way is a basic principal of passive solar design and may be appropriate in the mountain climates of California.

Figure 14 shows examples of mass walls commonly used in school construction.

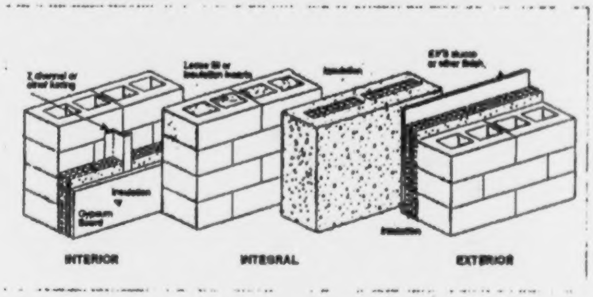

Z channel or other furring
Loose fill or insulation inserts
Insulation
EIFS stucco or other finish
Insulation
Gypsum Board
Insulation
INTERIOR
INTEGRAL
EXTERIOR

*Figure 14 – Mass Wall Constructions*

**Heat Capacity**

Heat capacity (HC) is the metric used to quantify thermal mass. HC is the amount of heat in Btu that must be added to one square foot of surface area in order to uniformly elevate the temperature of the construction by one degree Fahrenheit. The units are Btu/ft$^2$·°F. HC is the sum of the heat capacity of each individual layer in the wall. The heat capacity of each layer is the density of the material times its thickness times its specific heat (all in consistent units). HC can be approximated by multiplying the weight of a square foot of wall, roof or floor by 0.2. For example, a wall with a weight of 100 lb/ft$^2$ has an HC of approximately 20 are Btu/ft$^2$·°F.

Many energy standards (including California Title 24) consider HC as a factor in the overall performance of a building envelope component. The California nonresidential standards, for instance, have separate U-factor criteria for different HC ranges. ASHRAE/IESNA

Standard 90.1-1999 has a mass wall class of construction with separate criteria for this class of construction.

Most concrete materials are not very good insulating materials. However, some are better than others. There is a class of materials called aerated concrete that has air bubbles entrained in the concrete, which make the concrete lighter and also improve its insulating ability.

### Cool Roofs

Heat transfer is also affected by the exterior surface. This is especially important for roofs. In fact, the term cool roofs is used to describe those with favorable surface characteristics. Cool roofs have two key features. First, they have a high solar reflectivity, which usually means that they are light in color. The high reflectivity means that solar radiation is reflected rather than absorbed by the roof surface, keeping the surface temperature lower and reducing heat gain. Second, cool roofs have a high or normal emittance. Emittance is a little harder to understand than reflectivity, but it can be just important to energy performance. Galvanized metal and other metallic finishes have a low emittance, which means that when they warm up they can't easily release their heat by radiating it back to the sky.

### Radiant Barriers

One last feature of construction assemblies that deserves some discussion is radiant barriers. Many construction assemblies have a cavity. An attic, for instance, is a cavity separating the roof from the ceiling. Un-insulated walls also have a cavity that separates the exterior sheathing from the interior wallboard. In construction assemblies that have a cavity, much of the heat transfer from the warmer surface to the colder surface is due to radiation. A radiant barrier can reduce this component of heat transfer. A radiant barrier is a shiny metallic surface on one or more sides of the cavity that has a low emissivity. Radiant barriers are commonly installed in attics.

## Applicable Codes

The California Nonresidential Energy Efficiency Standards (Title 24) apply to schools, and these standards require that roofs, walls and floors have a minimum level of insulation. The criteria are expressed both in terms of a minimum R-value and a maximum U-factor. If you install the prescribed level of insulation, then it is not necessary to make U-factor calculations. For unusual constructions, the maximum U-factor criteria offers more design flexibility.

The requirements vary by climate region and are summarized in Table 17. Roofs must be insulated with at least R-11 insulation in the south coast region, while a minimum of R-19 is required in the other California climate regions. Walls require R-11 along the coast, but R-13 for the valley, desert and mountains. R-19 floor insulation is required in the mountains and R-11 in the other climate regions.

*Table 17 – Title 24 Standards for Building Envelope*

| | | South Coast | North Coast | Central Valley | Desert | Mountains |
|---|---|---|---|---|---|---|
| Roofs | R-value | 11 | 19 | 19 | 19 | 19 |
| | U-value | 0.078 | 0.057 | 0.057 | 0.057 | 0.057 |
| Walls | R-value | 11 | 11 | 13 | 13 | 13 |
| | Wood frame | 0.092 | 0.092 | 0.084 | 0.084 | 0.084 |
| | Metal frame | 0.189 | 0.189 | 0.182 | 0.182 | 0.182 |
| | Mass ($7 \leq HC < 15$) | 0.430 | 0.430 | 0.430 | 0.430 | 0.340 |
| | Mass ($15 \leq HC$) | 0.690 | 0.650 | 0.650 | 0.400 | 0.360 |
| | Other | 0.092 | 0.092 | 0.084 | 0.084 | 0.084 |
| Floors | R-value | 11 | 11 | 11 | 11 | 19 |
| | Mass ($7.0 \leq HC$) | 0.158 | 0.158 | 0.097 | 0.158 | 0.097 |
| | Other | 0.076 | 0.076 | 0.076 | 0.076 | 0.050 |

Source: California 1998 Nonresidential Energy Efficiency Standards (Title 24)

## Design Tools

There are many different ways to calculate the thermal performance of construction assemblies. The appropriate method depends on the type and complexity of construction. The basic calculation methods include:

- *Series Calculation Method.* This is the easiest way of calculating U-factor, but its use is limited to constructions that have no framing and are made of homogenous materials.
- *Parallel Path Calculation Method.* This simple extension of the series calculation method can be used for wood-framed assemblies.
- *Effective R-value (Isothermal Planes).* This method uses principles similar to the series and parallel path calculation methods, and is appropriate for construction assemblies such as concrete masonry and metal framed walls/roofs where highly conductive materials are used in conjunction with insulated or hollow cavities.
- *Two-dimensional Calculation Method.* Two dimensional heat flow analysis may be used to accurately predict the U-factor of a complex construction assembly. Calculating two-dimensional heat flow involves advanced mathematics and is best performed with a computer.
- *Testing.* This is the most accurate way to determine the U-factor for all types of construction, except slabs-on-grade. But it is costly and time consuming, and because there are a large variety of possible construction assemblies, it is impractical to test them all. It's usually more cost-effective to use calculation methods.

Table 18 has guidelines on which method can be used with different types of construction assemblies. These methods are described in greater detail in the electronic Appendix to the Best Practices Manual.

*Table 18 – Procedures for Determining U-factors for Opaque Assemblies*

| | Series Calculation Method | Parallel Path Calculation Method | Effective R-value (Isothermal Planes) | Two-dimensional Calculation Method | Testing |
|---|---|---|---|---|---|
| **Roofs** | | | | | |
| Insulation above Deck | ✓ | | | ✓ | ✓ |
| Attic (wood joists) | | ✓ | | ✓ | ✓ |
| Attic (steel joists) | | | ✓ | ✓ | ✓ |
| Other | | | | ✓ | ✓ |
| **Walls** | | | | | |
| Mass | | | ✓ | ✓ | ✓ |
| Wood Framed | | ✓ | | ✓ | ✓ |
| Steel Framed | | | ✓ | ✓ | ✓ |
| Other | | | | ✓ | ✓ |
| **Below-Grade Walls** | | | | | |
| Mass | | | ✓ | ✓ | ✓ |
| Other | | | | ✓ | ✓ |
| **Floors** | | | | | |
| Mass | ✓ | | ✓ | ✓ | ✓ |
| Steel Joist | | | ✓ | ✓ | ✓ |
| Wood Framed | | ✓ | ✓ | ✓ | ✓ |
| Other | | | | ✓ | ✓ |

### Computer Programs

The calculation methods described above are implemented in a number of design tools and computer programs.

- The EZFrame program, available from the California Energy Commission, can be used to calculate the U-factor of metal framed wall and roof constructions and accounts for many features such as the gauge of the steel used for framing members, the percent of knockouts in the web, and insulating tape between the framing members and the sheathing. The cost is $14.00. For more information, contact the California Energy Commission. Tel: (916) 654-5106 or (800) 772-3300. Web site: http://www.energy.ca.gov/efficiency/computer_prog_list.html.
- The Therm program available from LBNL is designed primarily to analyze window frames, but can be used for any type of two-dimensional heat transfer analysis. This program can be downloaded from http://windows.lbl.gov/software/therm/therm_getacopy.htm.
- General-purpose energy simulation programs such as DOE-2 and EnergyPlus can be used to calculate the energy savings of various construction assemblies. With these programs, the dynamics of heat transfer are modeled. In fact, EnergyPlus models the temperature gradient in constructions. DOE-2, on the other hand, uses a more simple response factor method.

### Pre-calculated Data

The U-factor of common constructions has been calculated and values are published in a number of sources.

- Appendix B of the 1998 *California Nonresidential Manual* has a wealth of useful data, including R-values of common materials, pre-calculated U-factors, and other data. The

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*Nonresidential Manual* can be downloaded from http://www.energy.ca.gov/title24/nonresidential_manual/index.html.

- Appendix A of ASHRAE/IESNA Standard 90.1-1999 has published values in both inch-pound and metric (SI) units. Constructions include walls, roofs, floors, slabs and below-grade walls. These values are also contained in the EnvStd 4.0 computer program, which can be downloaded from http://www.eley.com.

### Indoor Air Quality (IAQ) and Moisture

It is extremely important to provide an exterior weather barrier to prevent moisture from entering construction cavities. Wet or damp construction cavities, attics and plenums are a major source of mold and can contribute significantly to indoor air quality problems. In addition, moisture can damage the structure and degrade the performance of insulation, increasing energy and operating costs. The California Air Resources Board reports that most of the IAQ complaints that they receive with regard to schools are related to leaky roofs that have resulted in the growth of mold in a plenum or attic space.

Water can also enter construction cavities through a process of moisture migration. Moisture migrates from the warm and humid side of the construction assembly to the cold dry side of the construction assembly. The moisture cools as it moves through the wall and may condense into water molecules that can accumulate to cause damage and create mold. To prevent moisture migration, framed walls, floors and roofs should have a vapor barrier on the warm moist side. For California climates, this means that the vapor barrier should be on the interior side. Vapor barriers are available as part of most insulation products and consist of an asphalt impregnated paper or metal foil. Care should be taken during construction to ensure that this vapor barrier is continuous, tightly secured at the framing members and not damaged. Special care should be taken in lockers, showers, food preparation areas, and other spaces that are likely to have high humidity.

In addition to correctly installing a vapor retarder, it is important to provide adequate ventilation of spaces where moisture can build up. Most building codes require that attics and crawl spaces be ventilated, and some require a minimum one-inch clear airspace above the insulation for ventilation of vaulted ceilings. Even the wall cavity may need to be ventilated in extreme climates.

### Insulation Protection

Insulation should be protected from sunlight, moisture, landscaping equipment, wind, and other physical damage. Rigid insulation used at the slab perimeter of the building should be covered to prevent damage from gardening or landscaping equipment. Rigid insulation used on the exterior of walls and roofs should be protected by a permanent waterproof membrane or exterior finish. If mechanical or other equipment is installed in attics, access to this equipment should be provided in a way that won't cause compression or damage to the insulation. This may mean using walking boards, access panels, and other techniques to prevent damage to the insulation.

In situations where insulation is left exposed (including return air plenums), fiberglass insulation products should be encapsulated in a manner that prevents fibers from becoming air borne. To maintain a continuous vapor barrier, all seams should be sealed with tape. In this application, simply stapling the insulation is not adequate.

### Materials Efficiency and Other Environmental Considerations

One of the most effective ways to achieve materials efficiency in a building is to reuse all or part of an existing building enclosure. This reduces solid waste produced by a project and avoids the environmental burdens associated with production and delivery of materials for a new building enclosure. Saving the building enclosure, however, may not be appropriate if the existing structure is not energy efficient and cannot be adequately upgraded to meet high performance objectives.

When designing a new building enclosure, materials efficiency can be achieved by:

- Using panelized, pre-cut, and engineered construction products
- Designing with standard dimensions to reduce on-site waste
- Designing a compact building (this also reduces impervious surface on the site, see Guideline SP1; but may conflict with daylighting objectives)
- Planning for future adaptability to extend the life of the building
- Choosing durable materials and systems

In addition, building enclosure and insulation materials are available that are recyclable, include recycled or resource-efficient content, or have other environmentally preferred characteristics. The materials may, for example, avoid introducing toxics into the building or natural environment, or they may be produced using sustainable methods. In addition to the design strategies above, refer to Table 19 below for some easily achievable strategies that will improve the sustainability of the building enclosure and insulation.

For specific product recommendations, see *GreenSpec: The Environmental Building News Product Directory and Guideline Specifications*, available at http://www.buildinggreen.com, and OIKOS's Redi Guide (Resources for Environmental Design Index), available from Iris Communications, (800) 346-0104, http://www.oikos.com.

*Table 19 – Strategies for Constructing Resource-efficient Building Enclosures*

| *Building Component* | *Strategies* | *Environmental Benefits & Considerations* |
|---|---|---|
| Foundation and Concrete Work | For concrete materials, specify flyash as replacement, not addition. 10–25% replacement is commonly specified, but higher percentages are possible, depending on application. | Formerly landfilled as an industrial waste, flyash is now used to replace energy-intensive Portland cement in concrete mix. Flyash adds workability and strength. CIWMB recommends using "high volume" flyash concrete (with 50% flyash). |
| | Use autoclaved and/or aerated concrete for appropriate concrete applications. | Aerated concrete is lighter and has better insulating properties than standard concrete. |
| | Prohibit dumping concrete waste anywhere intended to be pervious. | Prevents degradation of the site and permits infiltration. |
| | Use steel rather than wood forms. | Although energy intensive, steel is reusable, contains recycled content and can be recycled at the end of service life. |
| | If wood forms are used, reuse wood in framing and sheathing. | Reduces resources used. Reduces waste. |
| | Use low and non-toxic form releases. Bio-based products are available. | Prevents soil contamination, and reduces human health risk. Promotes worker safety. Water-based products should be protected from freezing during storage. |
| | Use expansion joint fillers with recycled content. | Appropriate use of recycled, relatively low-strength materials, such as waste cellulose from recycled newspapers. |
| | Use rebar supports with recycled content. DOT-approved products are available with 100% recycled content, including engineered plastics and fiberglass. | Rebar supports in concrete form-work have minimal structural requirements; appropriate use of recycled waste plastic. |
| | If using ICFs, use options with ozone-friendly foam ingredients. (ICFs are permanent forms with integral insulation that are not disassembled after the concrete is cured. Note: not all ICFs are alike; field R-values can differ significantly so rely on results from completed projects.) | ICFs can provide significant improvements in energy efficiency, can reduce the use of energy-intensive Portland cement. Using ozone-friendly options (with EPS foam) eliminates a source of global warming. |

*Table 19 – Strategies for Constructing Resource Efficient Building Enclosures (Continued)*

| *Building Component* | *Strategies* | *Environmental Benefits & Considerations* |
|---|---|---|
| Masonry Walls | Use mortar dropping control product to prevent blocking of weep holes. Product available with 100% recycled polyethylene. | Maintains air flow and allows moisture migration from behind masonry veneer facades. Improves building durability. |
| | For CMUs: maximize recycled content. Typically available with 10% recycled content. | Reduces resources used to produce new CMU material. No difference in product performance or application. |
| | For CMUs: use CMUs containing flyash. | Formerly landfilled as an industrial waste, flyash is now used to replace energy-intensive Portland cement in concrete mix. Flyash adds workability and strength. |
| | For CMUs: consider using lightweight CMUs. | Reduces transportation-related impacts. |
| | For CMUs: pull watermark line down below window framing to eliminate finishing details. | Reduces maintenance over the life of the building. |
| | For CMUs: don't paint, order with color. | Avoids resources used to produce paint. Avoids use of VOC-emitting paints generally used to finish CMUs. |
| Steel Framing | Use systems with highest level of recycled content. Although steel may have as little as 25% recycled content, most structural steel framing has as much as 90% or more. Many load-bearing stud systems include up to 60% recycled content. | High recycled content steel uses less embodied energy, and minimizes mining waste and pollution associated with virgin steel production. Also generally reduces job site waste, as waste steel is highly recyclable. Transportation of steel uses less energy and creates less pollution compared to dimensional lumber due to weight.<br>Steel conducts heat efficiently. When using light-gauge steel, ensure that insulation is adequate to prevent thermal bridging and heat loss. |
| | Use fireproofing available with recycled EPS foam and recycled newsprint. | Traditionally, products contained fiberglass and asbestos for this use. More benign products that make efficient use of recycled materials are preferable. |
| Wood Framing | Use advanced or intermediate framing systems where applicable and accounting for seismic requirements for building site. Example framing elements include 24" on-center framing, insulated headers, two stud corners with drywall clips, ladder partitions. References: *Builder's Guide* – Building Science Corporation, and *Efficient Wood Use in Residential Construction* – Natural Resources Defense Council. | This both allows for more insulation, less "cold" spots, and increased wood efficiency, thus improving both energy and materials efficiency. |
| | Use engineered wood products in place of dimensional lumber such as floor joists and roof joists. | Engineered wood products are lighter weight and use fewer resources for the same function as dimensional timbers. |
| | Use wood certified with Forest Stewardship Council (FSC) or Scientific Certification Service (SCS). A variety of certified dimensional and engineered wood products are available. | Prevents degradation to forest and wildlife habitat. |

*Table 19 – Strategies for Constructing Resource Efficient Building Enclosures (Continued)*

| *Building Component* | *Strategies* | *Environmental Benefits & Considerations* |
|---|---|---|
| Siding | Use fiber cement siding. Most available factory primed; suggest back priming. Proper painting is important for the siding's long-term durability. | Reduces virgin wood use and can be a durable option. |
| Roofing | Use metal roofing. | Includes recycled content, is durable, and can be recycled at the end of service life. |
| | Use non-PVC options for membrane roofing. | Avoids the environmental impacts of PVC manufacturing. |
| | Use "green roof" system for low-slope roofs. These roof systems are thicker than conventional roofs and include drainage, geotextile, soil, and vegetation layers. | Can detain rainwater reducing peak loads on sewer systems, helps reduce building heat gain and prevents urban "heat islands. Plantings also absorb carbon dioxide.<br>"Green roofs," however, require structural steel to support their weight. Because steel has high embodied energy, this may offset some of the environmental benefits of using "green roofs." |
| Moisture and Waterproofing | Sealants and repellants: Limit use of sealants through proper detailing. Use least-toxic options. Avoid products containing methylene chloride, chlorinated hydrocarbons, aromatic and aliphatic solvents, styrene butadiene, or products containing bactericides and fungicides classified as phenol mercury acetates, phenol phenates, or phenol formaldehyde. | Combining good detailing and low toxicity will prevent air quality problems while promoting long service life of the building. |
| | Do not rely on caulking for waterproofing. Proper flashing will prevent water from entering the building. | In addition to adding durability to shell, proper flashing prevents mold and mildew build up, reducing health risk. |
| | If using a vapor retarder, select film available with up to 100% LDPE (plastic). | Utilizes plastic waste that would otherwise be landfilled. Reduces resources required to produce virgin-based material. |
| Insulation | Use fiberglass insulation with up to 30% verified (SCS) recycled content. California plants use glass collected in CA recycling programs. Formaldehyde-free fiberglass option also available (price premium). | Uses glass collected at curbside recycling programs. Formaldehyde-free option promotes good indoor air quality and promotes worker safety. |
| | Use cellulose insulation produced with 100% recycled newsprint. | Utilizes paper waste that would otherwise be landfilled. |
| | If using rigid insulation with polyisocyanurate foam, use ozone-friendly option. | Prevents further degradation of the earth's atmosphere through global warming. |
| Exterior Doors (for window recommendations see Daylighting and Fenestration chapter.) | Use doors produced with reclaimed lumber. | Reduces pressure on timber supply, as well as degradation of forest habitat. |

Source: Adapted from *GreenSpec: The Environmental Building News Product Directory and Guideline Specifications*

# Guideline IN1: Wall Insulation

## Recommendation

Insulate exterior walls at a level appropriate for each class of construction and climate.

| Class of Wall | South Coast and North Coast Climates | Central Valley, Desert and Cold Climates |
|---|---|---|
| Wood Framed Walls | Insulate 2x4 wood framed walls with R-13 fiberglass batt insulation or use other insulating materials with a similar thermal resistance. When 2x6 wood framing is needed for structural (or other) reasons, insulate with at least R-19 fiberglass insulation. | Use 2x6 wood studs and advanced framing techniques to increase the percent of insulated cavity in walls. Insulate the cavities with R-19 batt insulation or other materials with a similar thermal resistance. |
| Steel Framed Walls | Insulate 2x4 steel framed walls with R-13 fiberglass batt insulation or other materials with a similar thermal resistance. When 2x6 framing is needed for structural (or other) reasons, insulate the cavities with at least R-19 fiberglass insulation. | Provide a continuous thermal barrier by installing a layer of continuous insulation on either the exterior or interior surface of the wall. Protect the insulation from physical damage and from moisture penetration. |
| Mass Walls | Shade mass walls from exposure to direct sun. Insulation is marginally cost effective in coastal climates. | Insulate mass walls either by furring on the interior surface, with an Exterior Insulation Finish System (EIFS), or with an integral insulation system. |

## Description

The construction of exterior walls affects comfort, operating costs, acoustic separation, and the size of heating and cooling systems. The class of construction (wood framed, steel framed or mass) is usually determined by requirements for fire separation between spaces, durability or other issues. The recommended insulation levels for these classes are based on life cycle cost analysis and are presented separately for each class and climate region. More insulation is justified in colder climates and less in more temperate climates.

Concepts of thermal heat transfer are presented in the overview to this chapter and the reader is encouraged to review these principles, since they apply to walls as well as other building enclosure components.

*Photo Courtesy: CertainTeed*

| Applicable Spaces | | Climates | | When to Consider | |
|---|---|---|---|---|---|
| Classrooms | ■ | South Coast | ■ | Programming | □ |
| Library | ■ | North Coast | ■ | Schematic | ▨ |
| Mulit-Purpose / Cafeteria | ■ | Central | ■ | Design Dev | ■ |
| Gym | ■ | Mountains | ■ | Contract Docs | □ |
| Corridors | ■ | Desert | ■ | Construction | □ |
| Administration | ■ | | | Commissioning | □ |
| Toilets | ■ | | | Operation | □ |
| Other | ■ | | | | |

## Applicability

These recommendations apply to all exterior walls in all spaces that are heated or cooled. Design decisions that affect wall thickness must be considered in the schematic design phase of the project.

## Applicable Codes

- For both metal and wood framed walls, the California Building Code requires R-11 insulation in the north and south coast climates and R-13 insulation in the other climate zones. Criteria for framed walls are provided as both a minimum R-value and a maximum U-factor. Only U-factor criteria are provided for mass walls and less insulation is required than for framed walls. See the Overview to this chapter.
- Fire protection codes (the California Building Code) require noncombustible construction for certain classes of schools, which prohibits wood framing. In some instances, walls must provide a four-hour fire separation near property lines and in other applications, which generally requires mass walls.

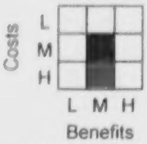
- Structural and seismic safety requirements often dictate the thickness and spacing of framing members. For masonry walls, they usually require at least partial grouting of all exterior walls.

*Rigid Insulation is the most effective way to insulate metal studs. Photo Courtesy: CertainTeed*

### Integrated Design Implications

Well-insulated and sealed walls can reduce drafts and thermal loads in buildings. This can result in smaller HVAC equipment and reduced costs.

### Costs



The cost of insulating the cavity of wood and steel framed walls is low, however insulating mass walls is more difficult and costly. Insulating the cavity of mass walls is not very effective because of thermal bridges across the concrete webs and seismic safety requires that most of the hollow cells be grouted and reinforced. The most effective way to insulate mass walls is to use an Exterior Insulation Finish System (EIFS), which costs $7/ft² for 1-inch insulation and $8/ft² for 2-inch insulation. If budget permits this is the preferred method, since the benefits of the thermal mass are maximized. As an alternative, steel or wood furring can be used on the interior of the wall, batt insulation can be placed in the cavities between the furring strips and gypsum board can be used as the interior finish.

### Benefits

Insulating walls has several important benefits for high performance schools:

- Energy use is reduced.
- Natural ventilation can be used for a greater number of hours.
- Smaller HVAC equipment can be purchased, which can reduce initial cost.
- Greater acoustic separation is provided from the outdoors.
- Spaces are more comfortable because the interior surface temperature will be closer to room temperature, which provides more uniform interior temperatures and can reduce drafts.

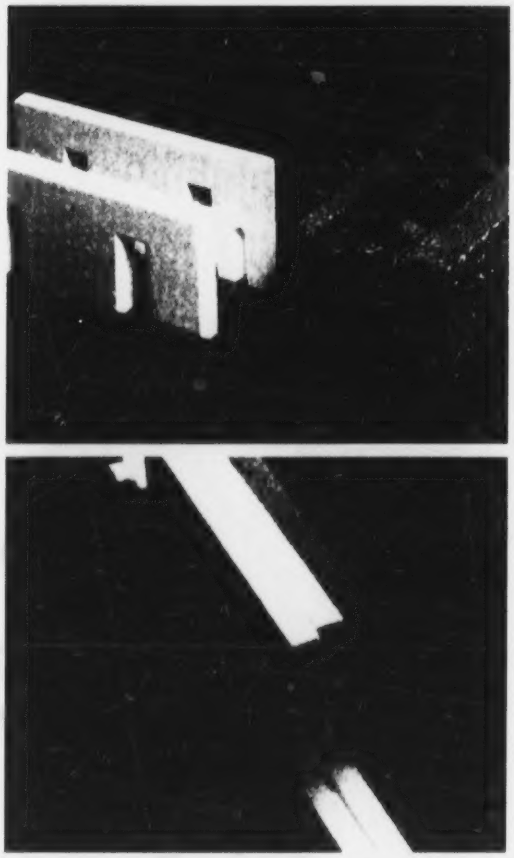
### Design Tools

The overview section of this chapter has a discussion of methods and procedures for calculating U-factors. Energy simulation programs are recommended for analyzing insulation options for mass walls, because of the time delays and dynamic effects inherent with this type of construction.

*Masonry walls can be insulated on the interior, but the benefits of thermal mass are mostly lost. Photo Courtesy: CertainTeed*

### Design Details

- For framed walls, provide a continuous vapor barrier on the inside surface of all walls. If the vapor barrier that comes with batt insulation is used, then the paper or foil should be stapled to the face of the studs, not the inside. This will provide a more secure and continuous vapor barrier and will reduce compression of insulation.
- For wood framing in the central valley, desert and cold climates, use 2x6 advanced framing. The studs should be spaced at 24" o. c., the headers over doors and windows should be insulated with rigid insulation, and minimum wood framing should be used at corners, wall intersections and openings.
- EIFS systems used with mass walls should be installed according to manufacturers instructions. Make sure that the exterior finish is durable and weather resistant.
- Electrical and mechanical equipment should be minimized for exterior walls. Equipment such as electrical outlets and other recessed equipment can create thermal bridges and increase infiltration.
- For wood framed walls, use wood products that are produced through sustainable forest practices. This can be achieved by requiring that framing members be certified by the Forrest Stewardship Council (FSC).
- For metal-framed walls, specify that the steel used for manufacturing have a 30% recycled content.



*Integral Mass Wall Insulation Techniques. Photo Courtesy: Korfil CBIS.*

### Operation and Maintenance Issues

Exterior and interior wall finishes must be maintained. The interior finish should be maintained for aesthetic reasons, but also light colors should be maintained to enhance the performance of the electric lighting and daylighting systems. Exterior surfaces should be maintained to be waterproof and secure. This is important to prevent water from entering construction cavities, which can cause the growth of mold, damage the structure, and deteriorate the performance of thermal insulation. Mold can be a major source of indoor air quality and needs to be avoided.

### Commissioning

No commissioning of exterior walls is needed other than normal construction administration.

### Example(s)

Some form of wall insulation is common in all schools.

### References / Additional Information

See Overview section of this chapter.

# Guideline IN2: Roof Insulation

## Recommendations

Insulate roofs at a level appropriate for each class of construction and climate. The recommended roof insulation depends on the class of construction and the climate. See also the guidelines for cool roofs and radiant barriers.

| Roof Class | South Coast North Coast | Central Valley Desert Cold |
|---|---|---|
| Insulation Above Deck including mass | Provide a continuous layer of R-7 rigid insulation over the structural deck and protect this with a durable weatherproof membrane. | Provide a continuous layer of R-14 rigid insulation over the structural deck and protect this with a durable weatherproof membrane. |
| Wood Framed, Attics and Other | Install R-30 blown in insulation in ventilated attics. Use R-30 batt insulation in other framed cavities. | Install R-38 blown in insulation in ventilated attics. Use R-38 batt insulation in other framed cavities. |

## Description

The construction of roof assemblies affects comfort, operating costs, acoustic separation, and the size of heating and cooling systems. The class of construction (wood framed, steel framed or mass) is usually determined by requirements for fire separation between spaces, durability or other issues. The recommended insulation levels for these classes are based on life cycle cost analysis and are presented separately for each class and climate region. More insulation is justified in colder climates and less in more temperate climates.

Concepts of thermal heat transfer are presented in the overview to this chapter and the reader is encouraged to review these principles, since they apply to roofs as well as other building enclosure components.

*Photo courtesy: CertainTeed*

## Applicability

This roof insulation guideline is applicable for all spaces in schools that are heated or cooled. The class of construction is usually determined in schematic design, but the insulation level can be set in design development or even contract documents.

| Applicable Spaces | | Climates | | When to Consider | |
|---|---|---|---|---|---|
| Classrooms | ■ | South Coast | ■ | Programming | ☐ |
| Library | ■ | North Coast | ■ | Schematic | ▨ |
| Mulit-Purpose / Cafeteria | ■ | Central | ■ | Design Dev | ■ |
| Gym | ■ | Mountains | ■ | Contract Docs | ☐ |
| Corridors | ■ | Desert | ■ | Construction | ☐ |
| Administration | ■ | | | Commissioning | ☐ |
| Toilets | ■ | | | Operation | ☐ |
| Other | ■ | | | | |

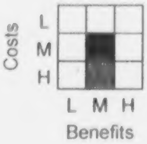
## Applicable Codes

- The California Building Code requires R-11 in the south coast climates and R-19 insulation in the other climate zones. Criteria are provided as both a minimum R-value and a maximum U-factor. See the Overview to this chapter for a more comprehensive discussion of the codes applicable in California.
- Fire protection codes (the California Building Code) require noncombustible construction for certain classes of schools, which may prohibit wood framing in roof assemblies.
- Structural and seismic safety requirements often result in the roof being used as a structural diaphragm to resist twisting or buckling during earthquakes or extreme wind.

## Integrated Design Implications

Well-insulated roofs and roof cavities can reduce drafts and thermal loads in buildings. HVAC ducts located in ceiling cavities can be leaky and can be a significant component of thermal loads. These losses are far less significant when ducts are located in sealed and insulated ceiling cavities. Reduced loads can result in smaller HVAC equipment and reduced costs.

## Costs



The cost of roof insulation varies with the class of construction. Insulating attics and the cavity of wood and steel framed roof assemblies is low since labor is minimal and the roof cavity is readily accessible during construction. Rigid insulation installed over structural decks is more expensive because of construction details and the added cost of rigid insulation.

## Benefits

Insulating roofs and ceilings has several important benefits for high performance schools:

- Energy use is reduced.
- Natural ventilation can be used for a greater number of hours.
- Smaller HVAC equipment can be purchased, which can reduce initial cost.
- Spaces are more comfortable because the interior surface temperature will be closer to room temperature, which provides more uniform interior temperatures and can reduce drafts.

## Design Tools

The overview section of this chapter has a discussion of methods and procedures for calculating U-factors. Energy simulation programs are recommended for analyzing insulation options for mass roofs, because of the time delays and dynamic effects inherent with this type of construction.

## Design Details

- Insulation installed in exposed applications or in return air plenums should not be exposed. Use insulation products that are either encapsulated or otherwise sealed from contact with moving air.
- Make sure that insulation is dry before walls or other cavities are enclosed. Moisture in building cavities can be a source of mold, which can cause building damage and be a source of indoor air contamination.
- Do not install insulation over suspended ceilings. This is because the insulation's continuity is likely to be disturbed by maintenance workers. Also, a suspended ceiling is a poor barrier to infiltration. If the insulation is located at the ceiling, many building codes will consider the space above the ceiling to be an attic and require that it be ventilated to the exterior. If vented to the exterior, air in the attic could be quite cold (or hot) and the impact of the leaky suspended ceiling would be made worse.
- Use type IC light fixtures in insulated gypsum board ceilings.
- Make sure that blowing agents used to manufacturer plastic foam insulations do not contain ozone-damaging CFCs.
- Consider recycled insulation materials for attics and other places where loose-fill insulation is used. If cellulose (recycled paper) is used, make sure that the chemicals used as a fire retardant contain no volatile organic compounds and are not a possible source of pollution.

### Operation and Maintenance Issues

The roof membrane must be maintained to prevent moisture from entering the roof cavity. Moisture in ceiling/roof constructions is a common source of mildew, which can cause serious indoor air quality problem. Insulation materials themselves require no maintenance.

### Commissioning

No commissioning is needed for roof insulation systems.

### Example(s)

Roof insulation is common in all schools.

### References / Additional Information

See Overview section of this chapter.

# Guideline IN3: Cool Roofs

## Recommendation

Use a roof surface that is light in color (high reflectance), yet has a non-metallic finish (high emissivity). Asphalt roofs with a cap sheet and modified bitumen roofs should be coated with a material having an initial reflectance greater than 0.7 and an emittance[21] greater than 0.8. Single ply roofing material should be selected with the same surface properties.

## Description

Solar gain on roofs is a significant component of heat gain and using materials that have a high reflectance and a high emittance can significantly reduce the load. The high reflectance keeps much of the sun's energy from being absorbed. The high emittance allows radiation to the sky. Cool roofs are typically white and have a smooth texture. Commercial roofing products that qualify as cool roofs fall in two categories: single ply and liquid applied. Examples of single ply products include:

- White EPDM (Ethylene-Propylene-Dieneterpolymer Membrane)
- White PVC (polyvinyl chloride)
- White CPE (chlorinated polyethylene)
- White CPSE (chlorosulfonated polyethylene, e.g. Hypalon)
- White TPO (thermoplastic polyolefin)

Liquid applied products may be used to coat asphalt cap sheets, modified bitumen and other substrates. Products include:

- White elastomeric coatings
- White polyurethane coatings
- White acrylic coatings
- White paint (on metal or concrete)

Cool roofs are becoming available in different colors. Table 20 shows reflectance and emittance for some typical roofing products.

A white single ply membrane with heat welded seams is being installed on this roof surface. Photo courtesy: BondCote Roofing Systems

| Applicable Spaces | | Climates | | When to Consider | |
|---|---|---|---|---|---|
| Classrooms | ■ | South Coast | ■ | Programming | ☐ |
| Library | ■ | North Coast | ■ | Schematic | ▨ |
| Mulit-Purpose / Cafeteria | ■ | Central | ■ | Design Dev | ■ |
| Gym | ■ | Mountains | ▨ | Contract Docs | ☐ |
| Corridors | ■ | Desert | ■ | Construction | ☐ |
| Administration | ■ | | | Commissioning | ☐ |
| Toilets | ■ | | | Operation | ☐ |
| Other | ■ | | | | |

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[21] Heat radiated from a roof surface is proportional to the 4th power of the absolute temperature and depends on emittance. Emittance is the ratio of radiant heat flux emitted by a specimen to that emitted by a black body at the same temperature and under the same conditions.

*Table 20 – Solar reflectance and emittance of different roofing materials.*

*Source: Berdahl and Bretz 1995, Akbari 1990,Parker et al. 1993, LBNL Cool Roofing Materials Database.*

| | Material | Total Solar Reflectance | Emittance |
|---|---|---|---|
| Reflective coatings | Kool seal elastomeric over asphalt shingle | 0.71 | 0.91 |
| | Aged elastomeric on plywood | 0.73 | 0.88 |
| | Flex-tec elastomeric on shingle | 0.85 | 0.89 |
| | Insultec on metal swatch | 0.78 | 0.90 |
| | Enerchon on metal swatch | 0.77 | 0.91 |
| | Aluminum pigmented roof coating | 0.30 - 0.55 | 0.42 - 0.67 |
| | Lo-mit on asphalt shingle | 0.54 | 0.42 |
| White metal roofing | MBCI Siliconized white | 0.59 | 0.85 |
| | Atlanta Metal products Kynar Snow White | 0.67 | 0.85 |
| Single-ply roof membrane | Black EPDM | 0.06 | 0.86 |
| | Grey EPDM | 0.23 | 0.87 |
| | White EPDM | 0.69 | 0.87 |
| | White T-EPDM | 0.81 | 0.92 |
| | Hypalon | 0.76 | 0.91 |
| Paint | White | 0.85 | 0.96 |
| | Aluminum paint | 0.80 | 0.40 |
| Asphalt shingles | Black | 0.03 - 0.05 | 0.91 |
| | Dark Brown | 0.08 - 0.10 | 0.91 |
| | Medium Brown | 0.12 | 0.91 |
| | Light Brown | 0.19 - 0.20 | 0.91 |
| | Green | 0.16 - 0.19 | 0.91 |
| | Grey | 0.08 - 0.12 | 0.91 |
| | Light grey | 0.18 - 0.22 | 0.91 |
| | White | 0.21 - 0.31 | 0.91 |

Note: Shaded products all have a reflectivity greater than 0.70 and an emittance greater than 0.80.

### Applicability

Cool roofs are applicable to all spaces in schools and to all California climates. The benefits are less, however, in the cold regions of the state. In order to take advantage of equipment downsizing, cool roofs should be considered in the schematic design phase.

### Applicable Codes

The California building code offers credits for cool roofs. Cool roofs are also considered in ASHRAE/IES Standard 90.1-1999 and state energy codes in Georgia, Florida, and Hawaii. The California credit can be used through either the building envelope trade-off option or the whole building compliance method.

### Integrated Design Implications

Cool roofs can significantly reduce cooling loads. This can result in smaller air-conditioning equipment or in some cases air conditioning can be eliminated entirely, in favor of natural ventilation. Like all roofing systems, skylights and other roof penetrations as well as the roof top equipment mounts should be considered in the design of the roof. Equipment access should be provided in a manner that does not create undue wear or damage to the roof membrane.

## Costs

The additional cost for coating an asphalt cap sheet or modified bitumen roof is about \$1.00 to \$2.00 per ft². The cost premium between a conventional single ply roof membrane and one with a high reflectance (all have high emittance) is negligible.

| Costs | L | M | H |
|---|---|---|---|
| L |  | ■ |  |
| M |  |  |  |
| H |  |  |  |

Benefits

## Benefits

Cool roofs can save demand charges and energy charges. They are highly cost effective, especially in the desert and central valley climates. However, there are other benefits as well. Since solar radiation (especially ultraviolet light) is a major cause of roof deterioration, cool roof coatings can significantly increase the life of the roof membrane. Cool roofs also can help make the whole community cooler by reducing the "heat island" effect.

## Design Tools

Cool roofs are effective for a number of complex reasons. They reflect heat from the sun, and assessing this benefit requires a model that accounts for the position and intensity of the sun. Sun that is absorbed by the roof (that which is not reflected) increases the surface temperature of the roof and induces heat gain in addition to that driven by temperature differences. At night and at other times, hot roof surfaces radiate heat to the night cool sky. This is a valuable benefit that requires knowledge of the roof surface temperature and the sky temperature. Because of the complexity of heat transfer related to cool roofs, energy simulation programs are necessary to accurately assess their benefits.

*This building uses a standing seam metal roof with a white coating. Photo courtesy: **Snap-Clad Metal Roofing and** Boarman Kroos Phister Rudin **& Associates***

## Design Details

- The performance of cool roofs is affected by the accumulation of dirt. Dirt accumulation can be reduced if roof surfaces slope at least ¼ inch per foot.
- When liquid applied coatings are used, carefully select coatings that are compatible with the underlying substrate.
- Liquid applied cool roof coatings should comply with ASTM Standard 6083-97 for durability and elongation and have a minimum thickness of 20 mils.

*Elastomeric or other coating can be field applied to many roof substrates. Photo courtesy: Dow Corning roofing products.*

## Operation and Maintenance Issues

To assure continued performance of cool roofs, they will need to be cleaned each year with a high-pressure water spray. Liquid applied coatings may need to be refinished every five years or so.

## Commissioning

No commissioning is needed.

## Example(s)

## References / Additional Information

Akbari H., et al. 1997. "Peak Power and Cool Energy Savings of High-Albedo Roofs". Energy and Buildings, Berkeley, CA. Vol. 25, pp. 117 - 126.

Akbari H. and S. Bretz. 1997. "Long Term Performance Of High-Albedo Roof Coatings". Energy and Buildings, Berkeley, CA. Vol. 25, pp. 159 - 167.

Akbari H., et al. 1995. "Mitigation of Urban Heat Islands: Materials, Utility Programs and Updates." Energy and Buildings, Berkeley, CA, Vol. 22, pp. 255 - 265. Also Lawrence Berkeley National Laboratory Report LBL-36587, Berkeley, CA.

Berdahl, P. and S. Bretz. 1997. "Preliminary Survey of the Solar Reflectance of Cool Roofing Materials," Energy and Buildings - Special Issue on Urban Heat Islands and Cool Communities, 25(2), pp. 149-158. Also, Lawrence Berkeley National Laboratory Report LBL-36020, Berkeley, CA.

Berdahl, 2000. "Cool Roofing Materials Database". Lawrence Berkeley National Laboratory, Berkeley, CA. http://eetd.LBL.gov/coolroof/

Gartland, L. 1999. " Cool Coatings Heat Up Savings". Trade Press Publishing Corporation. http://www.facilitiesnet.com/NS/NS3m9ai.html.

Parker D. S. et al. 1993. "Laboratory Testing of The Reflectance Properties of Roofing Materials". Florida Solar Energy Center Report FSEC-CR-670-93, Cocoa FL.

Parker D.S. and S.F. Barkazi. 1997. "Roof Solar Reflectance and Cooling Energy Use: Field Results from Florida." Energy and Buildings, Berkeley. CA, Vol. 25, pp. 105 - 115.

Simpson, J. R., and E. G. McPherson. 1997. "The Effects of Roof Albedo Modification on Cooling Loads of Scale Model Residences in Tucson, Arizona". Energy and Buildings, Berkeley, CA. Vol. 25, pp. 127 - 137.

Taha, H. 1997. "Urban Climates and Heat Islands: Albedo, Evapo-transpiration, and Anthropogenic Heat". Energy and Buildings, Berkeley, CA. Vol. 25, pp. 99 - 103.

US EPA. 1998. "Roof Products MOU - Version 1.0". The United States Environmental Protection Agency.

# Guideline IN4: Radiant Barriers

Photo courtesy: PARSEC Thermo-Brite

| Applicable Spaces | | Climates | | When to Consider | |
|---|---|---|---|---|---|
| Classrooms | ■ | South Coast | ■ | Programming | ☐ |
| Library | ■ | North Coast | ■ | Schematic | ■ |
| Mulit-Purpose / Cafeteria | ■ | Central | ■ | Design Dev | ■ |
| Gym | ☐ | Mountains | ☐ | Contract Docs | ■ |
| Corridors | ■ | Desert | ■ | Construction | ☐ |
| Administration | ■ | | | Commissioning | ☐ |
| Toilets | ■ | | | Operation | ☐ |
| Other | ☐ | | | | |

## Recommendation

Use a radiant barrier in conjunction with attic construction in schools. Also use low-emissivity radiant barrier paints on interior surfaces to reduce the mean radiant temperature.

## Description

A radiant barrier is a surface with a low emittance that is installed at the ceiling of attics. The radiant barrier surface is usually aluminum foil or another shiny metallic finish that has a low-emittance. There are a couple of installation methods. The least costly method is to use plywood or composition board with a film that is pre-applied to the board. An alternate, but more effective method is to drape foil over the rafters before the sheathing is installed (see photo at right).

Radiant barriers are effective because they reduce one of the major components of heat gain, which is radiation from the hot attic ceiling to the cooler attic floor. The amount of heat that is radiated from the attic ceiling to the floor is directly proportional to the emissivity of the surfaces. Uncoated plywood and most other conventional building materials have an emittance of about 0.8, while the surface of a radiant barrier has an emittance of around 0.1. The radiation component of heat transfer can, therefore, be as much as eight times lower than without a radiant barrier.

Radiant barriers are effective in reducing cooling loads, but not heating loads. Radiant barriers can also improve the system efficiency of HVAC air distribution ducts are located in attics. Duct losses during cooling mode are proportional to the temperature difference between air inside the duct and the temperature of the attic. Radiant barriers reduce the temperature of the attic during cooling conditions, and therefore, duct system efficiency is improved.

## Applicability

Radiant barriers are highly recommended in the central valley and desert climates of California. They can also be effective in coastal climates. They are recommended for attics over in any spaces that are cooled by air conditioners or natural ventilation. Radiant barriers should be considered no later than the design development phase so that the HVAC equipment may be appropriately downsized.

## Applicable Codes

The California Building Code, which applies to schools, does not recognize radiant barriers. However, the California standards for low-rise residential buildings require radiant barriers in central valley and desert climates.

### Integrated Design Implications

Radiant barriers directly reduce cooling loads, which can result in smaller air conditioners. HVAC air duct efficiency is also improved when air distribution ducts are located in attics.

### Costs

When applied to sheathing the cost premium for radiant barriers is on the order of $0.10 to $0.15 per ft². Cost is a little higher for draped installation, mainly because additional labor is required.

| Costs | L | M | H |
|---|---|---|---|
| L | | ■ | |
| M | | | |
| H | | | |

Benefits

### Benefits

Radiant barriers reduce cooling loads and energy costs. They can also result in smaller air conditioners, which can more than compensate for the added cost of the radiant barrier. Attics where radiant barriers are installed have a lower temperature, which results in improved HVAC duct efficiency and other benefits.

### Design Tools

Estimating the benefits of radiant barriers can be approximated by making an adjustment to the U-factor of the ceiling/roof construction. The problem with this approach is that radiant barriers only have a benefit in reducing cooling loads. In fact, they can have a slightly negative effect on heating loads, since solar gains are reduced which might be useful when schools are in a heating mode. The most accurate way to evaluate radiant barriers in attics is to use an hourly simulation model where the attic itself is modeled as a separate, unconditioned thermal zone, and where radiation transfer can be explicitly modeled. The only models with these capabilities are for research purposes and are difficult for practitioners to use. However, the U. S. Department of Energy is developing a tool called EnergyPlus, which will have these capabilities. EnergyPlus is expected to be available sometime in 2001.

### Design Details

- Choose radiant barrier surfaces that have an emittance less than 0.1, when tested in accordance with ASTM E408. When comparing products, select a product with the lowest emittance. Some have an emittance as low as 0.05.
- Install radiant barriers so that the shiny surface faces down so that dirt cannot easily accumulate on the surface. Dirt can depreciate performance.
- When using radiant barriers that are pre-applied to sheathing, make sure that care is taken to not damage the surface during shipping and installation.
- When using the draped method of installation, let the radiant barrier sag about an inch from the sheathing, creating an additional air gap. This accounts for the improved performance of the draped method of installation.

### Operation and Maintenance Issues

Radiant barriers rarely require any maintenance, unless they are damaged while other maintenance work is being performed in an attic.

### Commissioning

No commissioning is necessary.

### Example(s)

Ross Middle School, Ross, CA
Architect: Esherick Homsey Dodge & Davis

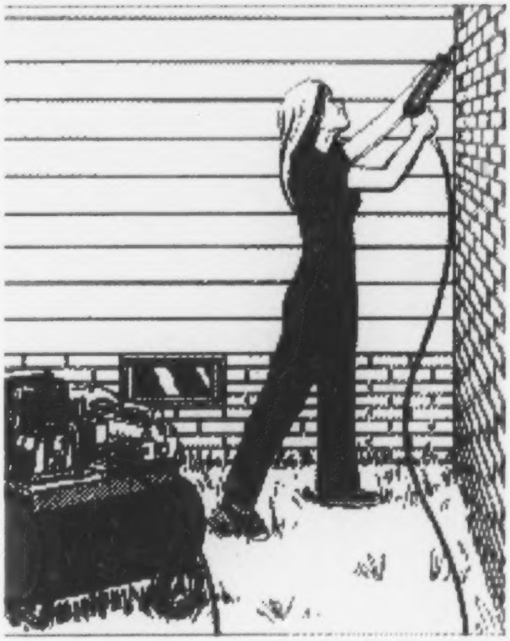
### References / Additional Information

U. S. Department of Energy, Radiant Barrier Fact Sheet, June 1991. Prepared by Oak Ridge National Laboratory.

The California Bureau of Home Furnishings (as part of insulation certification) certifies radiant barriers with an initial product emissivity of 0.05 or less.

The California ACM Approval Manual for low-rise residential buildings has detailed installation requirements in Section 4.24. This document is available at www.energy.ca.gov.

# Guideline IN5: Reduce Infiltration



Source www.DoItYourself.com

## Recommendation

The building envelope should be carefully designed to limit the uncontrolled entry of outside air into the building. This is achieved through building envelop sealing (caulking and weather stripping), specifying windows and doors that have been tested to have low rates of infiltration, and by using air lock entries in cold climates.

## Description

Controlling infiltration is important to achieving energy-efficient buildings. Air leakage introduces sensible heat into conditioned and semi-heated spaces. In climates with moist outdoor conditions, it is also a major source of latent heat. Latent heat must be removed by the air-conditioning system at considerable expense. The Standard has requirements for the sealing of building envelope elements, infiltration through doors and windows, air seals at loading dock doors, and vestibules to limit infiltration at main entrance doors to buildings.

## Applicability

Schools in all climates should be sealed to reduce infiltration, but it is especially important in the more harsh climates such as the cold, central valley and desert climates. The recommendations apply to all spaces in schools. Sealing and infiltration control should be first considered in the design development phase, but details should be specified in the contract documents. Tight construction is mainly a matter of care during construction and should be verified in the commissioning phase.

| Applicable Spaces | |
|---|---|
| Classrooms | ■ |
| Library | ■ |
| Mulit-Purpose / Cafeteria | ■ |
| Gym | ■ |
| Corridors | ■ |
| Administration | ■ |
| Toilets | ☐ |
| Other | ☐ |

| Climates | |
|---|---|
| South Coast | ▨ |
| North Coast | ▨ |
| Central | ■ |
| Mountains | ■ |
| Desert | ■ |

| When to Consider | |
|---|---|
| Programming | ☐ |
| Schematic | ▨ |
| Design Dev | ■ |
| Contract Docs | ▨ |
| Construction | ▨ |
| Commissioning | ▨ |
| Operation | ☐ |

## Applicable Codes

The California Building Code specifies minimum infiltration rates for fenestration products and requires that the building envelope be sealed to reduce unwanted infiltration.

## Integrated Design Implications

Poorly sealed buildings can cause problems for maintaining comfort conditions when additional infiltration loads exceed the HVAC design assumptions.

## Costs

The cost of controlling infiltration is minimal. Mainly it is a standard of care that must be exercised during the construction phase.

| Costs | L | M | H |
|---|---|---|---|
| L | ☐ | ■ | ☐ |
| M | ☐ | ☐ | ☐ |
| H | ☐ | ☐ | ☐ |
| | **Benefits** | | |

## Benefits

Controlling infiltration makes it easier to balance and maintain HVAC systems. Energy costs are also reduced in a cost effective manner.

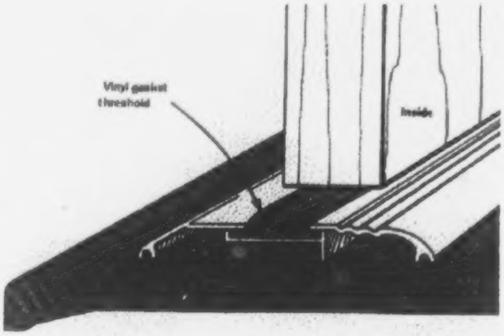
## Design Tools

All energy calculation methods are capable of accounting for infiltration in some manner. Some use an air-changes-per-hour method, while others are based on the concept of an effective leakage area (ELA). Many hourly simulation methods are capable of modeling infiltration using either calculation method. During construction, air leaks can be detected and repaired through pressurization tests, often called blower door tests. With this procedure, a building or space is pressurized with a large fan that is usually mounted in the door (thus, blower door). The space is pressurized to about 50 Pascals of pressure and leakage is measured. The location of leaks can be identified using smoke sticks.

## Design Details

### Building Envelope Sealing

Exterior joints, cracks, and holes in the building envelope shall be caulked, gasketed, weather stripped, or otherwise sealed. The construction drawings and specifications should require the sealing, but special attention is needed in the construction administration phase to assure proper workmanship. A tightly constructed building envelope is largely achieved through careful construction practices and attention to detail. Special attention should be paid to several areas of the building envelope includilng:



*Door weatherstripping. Source www.DoItYourself.com*

- Joints around fenestration and door frames
- Junctions between walls and foundations, between walls at building corners, between walls and structural floors or roofs, and between walls and roof or wall panels
- Openings at penetrations of utility services through roofs, walls, and floors
- Site-built fenestration and doors
- Building assemblies used as ducts or plenums
- Joints, seams, and penetrations of vapor retarders
- All other openings in the building envelope

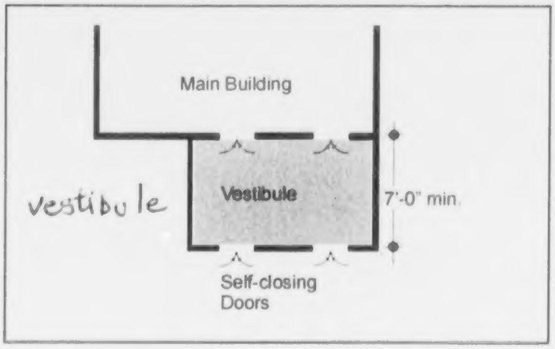
The Standard also has requirements for limiting infiltration through mechanical air intakes and exhausts. These requirements are addressed in the mechanical section (§ 6) of the Standard, not in the building envelope section.

### Fenestration and Doors

Fenestration products, including doors, can significantly contribute to infiltration. Most fenestration products should have an infiltration rate less than 0.4 cfm/ft². For glazed entrance doors that open with a swinging mechanism and for revolving doors, the infiltration should be limited to 1.0 cfm/ft². Infiltration rates should be verified with National Fenestration Rating Council 400. A laboratory accredited by the NFRC or other nationally recognized accreditation organizations must perform the ratings.

### Vestibules

In the cold California climates, vestibules should be created at the main entrance to schools. All the doors entering and leaving the vestibule must be equipped with self-closing devices and the distance between the doors should be at least 7 ft.



## Operation and Maintenance Issues

Weatherstripping around doors and other openings must be maintained and replaced every five to ten years. Caulking in exposed locations will need to be replaced or touched up each time the exterior of the school is painted.

## Commissioning

The commissioning agent should verify that weather stripping and caulking is properly installed. Fenestration products should be labeled by NFRC which will enable easy field verification of the infiltration requirements.

## Example(s)

All schools have infiltration control to some level.

## References / Additional Information

Nonresidential Manual for Compliance with the 1998 Energy Efficiency Standards, California Energy Commission, available from www.energy.ca.gov.

Installing Caulking and Weatherstripping, www.weservehomes.com/diy/ha_diy.html.

Weatherstripping to Reduce Heating and Cooling Bills, www.doityourself.com/energy/weatherstripping.htm.

# HVAC

This chapter presents guidelines for both natural ventilation and mechanical heating and cooling systems. The guidelines are presented together in one chapter to emphasis the interrelationship between these systems. The chapter begins with an overview that discusses thermal comfort, natural ventilation, outside air ventilation, applicable codes, design tools, controls, load calculations, systems sizing and other common elements. The overview also provides recommendations for system choice and selection. A series of technical guidelines follow the overview. These describe the technology or design strategy that is being recommended, its applicability to school spaces and climates, the integrated design implications, the costs and benefits, design tools that can be used to evaluate or further study the technology or design strategy, operation and maintenance issues and commissioning implications.

Guidelines are provided for the following technologies and design strategies:

- Cross Ventilation (Guideline TC1)
- Stack Ventilation (Guideline TC2)
- Ceiling Fans (Guideline TC3)
- Gas/Electric Split System (Guideline TC4)
- Packaged Rooftop System (Guideline TC5)
- Displacement Ventilation System (Guideline TC6)
- Hydronic Ceiling Panel System (Guideline TC7)
- Unit Ventilator System (Guideline TC8)
- Ductless Split System (Guideline TC9)
- Evaporative Cooling System (Guideline TC10)
- VAV Reheat System (Guideline TC11)
- Radiant Slab System (Guideline TC12)
- Baseboard Heating System (Guideline TC13)
- Gas-fired Radiant Heating System (Guideline TC14)
- Evaporatively Precooled Condenser (Guideline TC15)
- Dedicated Outside Air System (Guideline TC16)
- Economizers (Guideline TC17)
- Air Distribution Design (Guideline TC18)
- Duct Sealing and Insulation (Guideline TC19)
- Hydronic Distribution (Guideline TC20)
- Chilled Water Plants (Guideline TC21)
- Hot Water Supply (Guideline TC22)
- Adjustable Thermostats (Guideline TC23)
- EMS/DDC (Guideline TC24)
- Demand Controlled Ventilation (Guideline TC25)
- CO Sensors for Garage Exhaust Fans (Guideline TC26)

## Overview

The main purpose of HVAC systems is to maintain good indoor air quality and provide thermal comfort, two key requirements for high performance schools. HVAC systems are also one of the largest energy consumers in schools. Relatively small improvements in design or equipment selection can mean large savings in energy expenditures.

The choice and design of HVAC systems can affect many other high performance goals as well. Water-cooled air conditioning equipment is generally more efficient than air-cooled equipment, but increases water consumption. HVAC systems are also the major source of outside air ventilation in many schools, which makes their operation and maintenance mission critical for indoor air quality. Noise from the operation of HVAC systems and air whizzing through ducts and air diffusers can affect the acoustic environment of classrooms, libraries and other school spaces. Properly designed HVAC systems and controls can also be a key component of the "buildings that teach" theme.

## Integrated Design

To achieve a high performance design, it's very important to integrate HVAC with the building envelope and lighting system. Integrated design creates opportunities for greater comfort, lower first costs and lower operating costs. Here are some of the ways in which high performance can be achieved through integrated design:

- Careful attention to shading, building thermal mass and natural ventilation may eliminate the need for cooling in many parts of California.
- Natural ventilation can eliminate the need for ductwork, allowing higher ceilings and more daylighting savings.
- Under floor air distribution allows access for future power and communication needs. The system can also be designed to work in harmony with natural ventilation.
- Attention to the radiant temperature of surfaces through envelope design reduces heating energy requirements. This is especially true of windows.
- Using a central chilled water plant can allow for future installation of a thermal energy storage system or other peak electric demand reducing measures.
- Integration of HVAC and lighting occupancy sensor controls can reduce operating costs for both systems.

## Thermal Comfort

Thermal comfort is affected by air temperature, humidity, air velocity and mean radiant temperature (MRT).[22] Non-environmental factors such as clothing, gender,[23] age,[24] and metabolic activity also affect thermal comfort. Air temperature is what we measure with a normal thermometer, and most people are comfortable between about 68°F and 80°F, although an individual's preferred temperature is higher in the summer and lower in the winter, mostly because of differences between summer and winter wardrobes. The relative humidity range for human comfort is between about 30% on the low side and 60% on the high side, although these limits also depend on the air temperature and the season (summer or winter). Ceiling fans, circulation fans or operable windows, can provide air movement, and such air movement increases the upper temperature limit of comfort by about two degrees. The temperature of the surfaces surrounding a person (walls, ceiling, floor and windows) affects the radiant temperature (MRT). Caves have a low MRT, which makes them more comfortable even when the air temperature is high. Likewise, rooms with heated floors are comfortable, even through the air temperature may be lower than what is considered comfortable.

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[22] MRT is the temperature of an imaginary enclosure where the radiant heat transfer from a human body equals the radiant heat transfer to the actual non-uniform temperature surfaces of an enclosure.

[23] Women generally prefer temperatures about one degree warmer.

[24] Persons over 40 generally prefer temperatures about one degree warmer.

Although the most accepted definition of thermal comfort is ASHRAE Standard 55, recent research into thermal comfort is resulting in a reevaluation of this definition. Standard 55 currently defines comfort in terms of operative temperature and humidity and represents the range of thermal conditions when 80% of sedentary or slightly active people find the environment thermally acceptable (see Figure 15). Operative temperature is the average of the mean radiant and ambient air temperatures weighted by their respective heat transfer coefficients. The Standard 55 definition of comfort does not consider air movement or velocity.

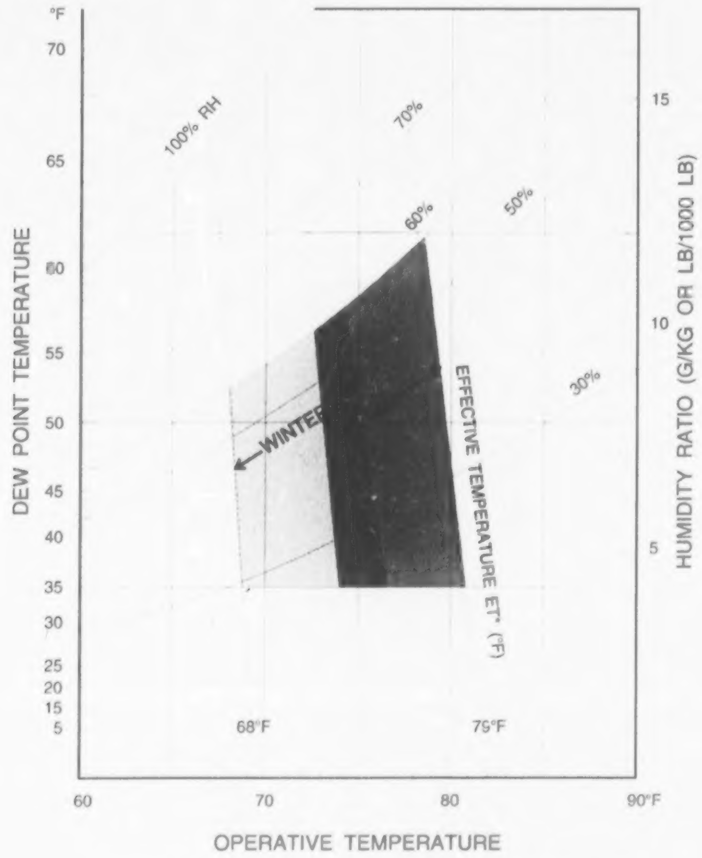

*Figure 15 – ASHRAE Standard 55 Comfort Envelope*

*Source: 1997 ASHRAE Handbook – Fundamentals. This figure shows the temperature and humidity ranges within which about 80% of the population will be comfortable while wearing typical summer and winter clothing and being in a sedentary or slightly active state.*

Much of the research on thermal comfort is based on asking people if they are hot or cold and correlating their response to measurements of air temperature, humidity, air velocity and MRT. The ASHRAE thermal sensation scale is commonly used for such surveys (see Table 21). Some of this research has been conducted in test environments where temperature and humidity can be tightly controlled. Other research has been conducted in people's workplaces.

*Table 21 – ASHRAE Thermal Sensation Scale*

| Cold | Cool | Slightly cool | Neutral | Slightly warm | Warm | Hot |
|---|---|---|---|---|---|---|
| -3 | -2 | -1 | 0 | +1 | +2 | +3 |

Since thermal comfort is not an absolute condition, but varies with each individual, statistical measures of thermal comfort are sometimes used. One statistical measure is the Predicted Mean Vote (PMV). PMV predicts the mean response of a large population on the ASHRAE thermal sensation scale (see Table 21). A PMV of +1 means that on average people are slightly warm, etc. PMV can be calculated if information is known about the metabolic rate, typical clothing, and environmental conditions such as temperature and humidity. Once PMV is known, it can be translated to another statistical factor called percent of population dissatisfied (PPD).

In addition to temperature, humidity, and mean radiant temperature, air movement also affects comfort. Operable windows, ceiling fans or circulation fans, affect air movement. Air velocities up to about 200 ft/minute are pleasant and enable most occupants to be equally comfortable at 2°F higher temperatures. Air speeds higher than about 200 ft/minute should be avoided because they can create drafts and be annoying (see Table 22).

*Table 22 – Effect of Air Movement on Occupants*

*Source: Victor Olgyay, Design with Climate, Princeton University Press, 1963*

| *Air Velocity* | *Probably Impact* |
|---|---|
| Up to 50 ft/minute | Unnoticed |
| 50 to 100 ft/minute | Pleasant |
| 100 to 200 ft/minute | Generally pleasant, but causes a constant awareness of air movement |
| 200 to 300 ft/minute | From slightly drafty to annoyingly drafty |
| Above 300 ft/minute | Requires corrective measures if work and health are to be kept in high efficiency |

Research by Gail Brager and others at the University of California, Berkeley, shows that students and teachers in naturally ventilated schools are comfortable for a wider range of thermal conditions than in schools that have continuous mechanical cooling. Occupants of air-conditioned schools develop high expectations for even and cool temperatures, and are quickly critical if thermal conditions drift from these expectations. Occupants in naturally ventilated schools adapt to seasonal changes in mean outdoor temperature and are comfortable for a wider range of conditions. They even prefer a broader range of thermal conditions. The comfort range for naturally ventilated buildings is considerably larger than common definition of comfort published in ASHRAE Standard 55-1992.

Research shows that part of the difference in comfort expectations is due to behavioral adaptations: occupants in naturally ventilated schools wear appropriate clothing and open windows to adjust air speeds. However, some of the difference is due to physiological factors. The human body's thermal expectations actually change through the course of a year, possibly because of a combination of higher levels of perceived control (occupants can open and close windows) and a greater diversity of thermal experiences in the building.

Using an adaptive model of thermal comfort, instead of the tight model recommended by ASHRAE Standard 55 allows schools to be designed and operated to both optimize thermal comfort and reduce energy use. In many climates, maintaining a narrowly defined, constant temperature range is unnecessary and expensive. Brager's research is the foundation of changes currently being considered to ASHRAE Standard 55.

### Potential for Natural Ventilation

Natural ventilation is an effective and energy efficient way to provide outside air ventilation and to provide cooling in many California schools. Historically, most schools in California have not been air-conditioned and natural ventilation has been the only means of cooling. The classic classroom has high windows to provide both natural ventilation and daylighting. In most California climates, natural ventilation is still a solid strategy, but windows must be designed to maintain a safe and secure facility while allowing air to enter and escape even at night and on weekends.

The potential for natural ventilation varies with climate. Figures 16 through 19 show the potential for maintaining thermal comfort in classrooms for four California climate regions. These diagrams have time of the day on the vertical axis and months of the year on the horizontal axis. The shades of gray in the diagrams represent the ASHRAE thermal sensitivity scale from neutral to slightly warm, to warm to hot.

The period of time when schools are typically operated is also shown. If a school is operated in the summer or for extended hours, adjustments can be made to these figures.

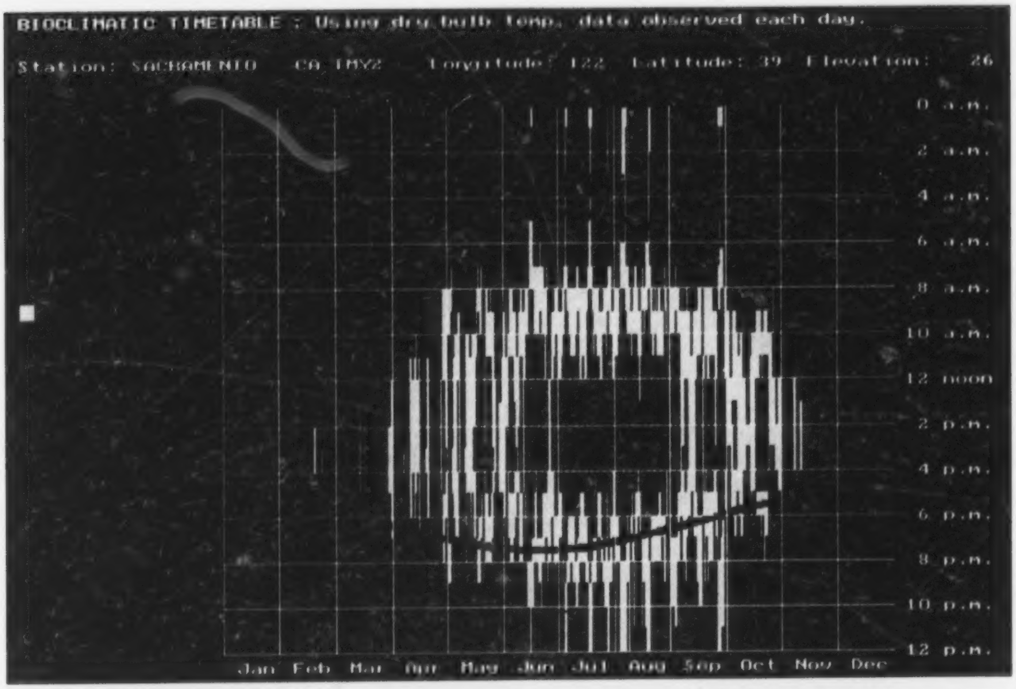

*Figure 16 – Natural Ventilation Potential, California Central Valley (Sacramento)*

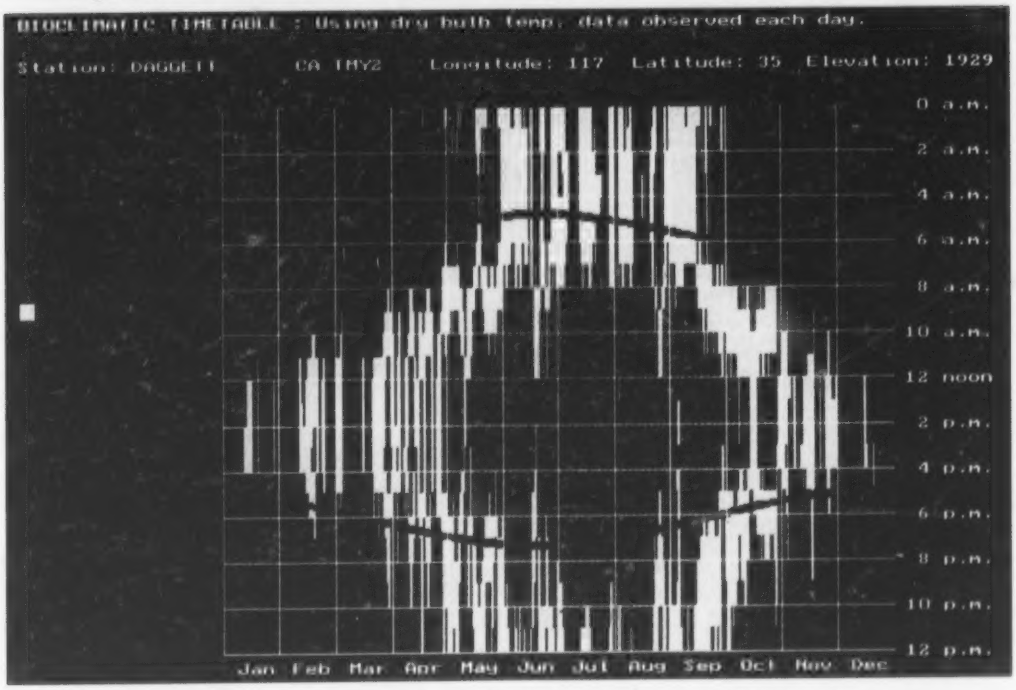

*Figure 17 – Natural Ventilation Potential, California Desert (Daggett)*

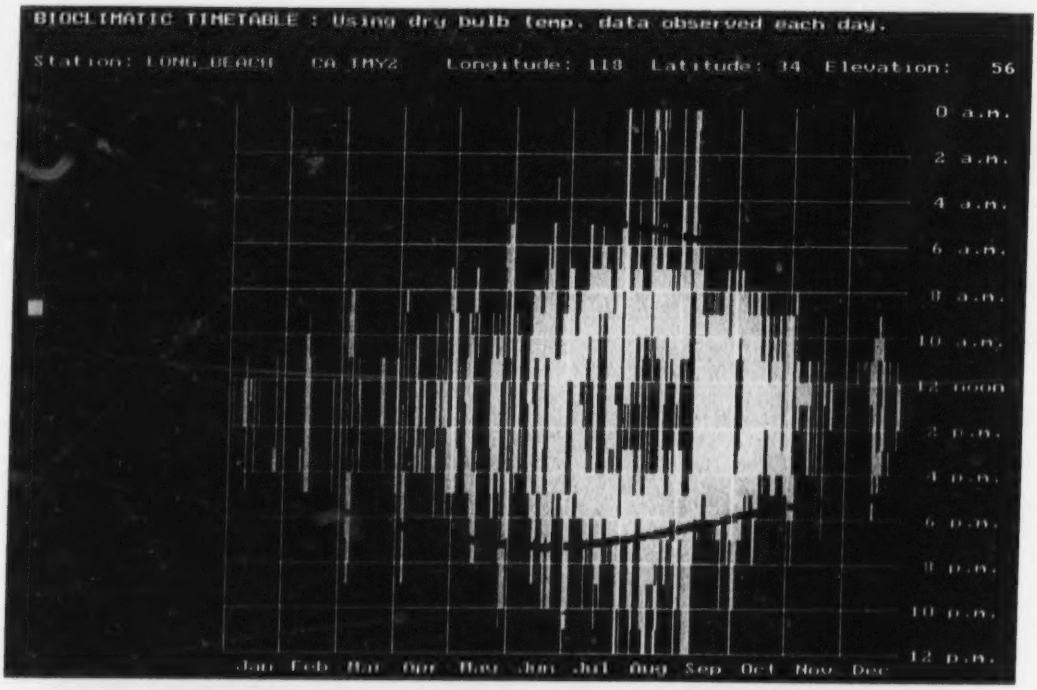

*Figure 18 – Natural Ventilation Potential, California South Coast (Long Beach)*

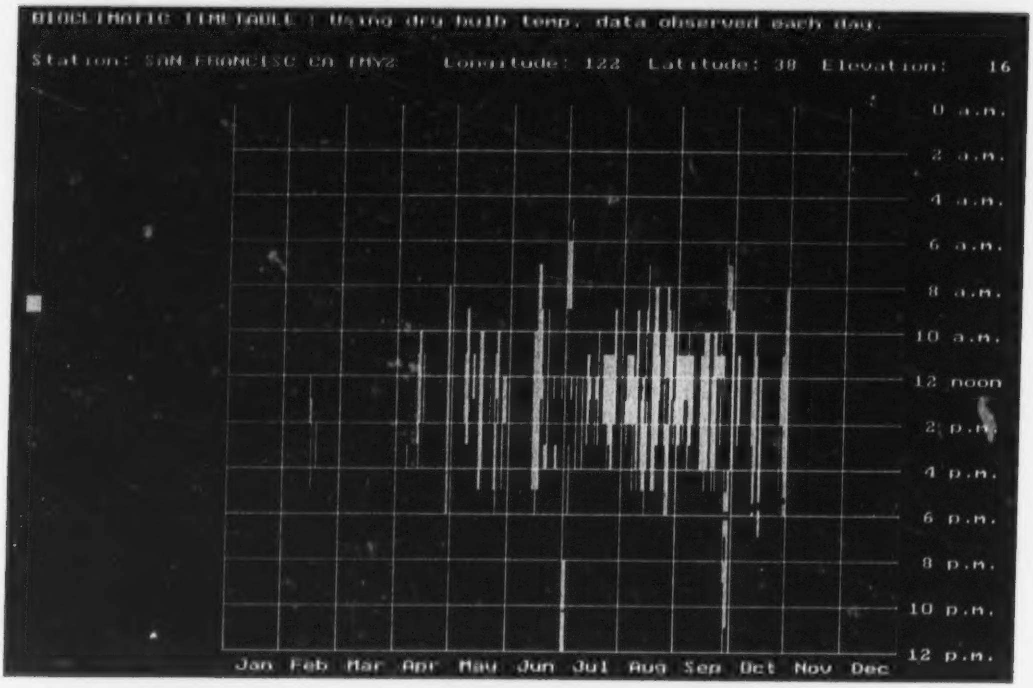

*Figure 19 – Natural Ventilation Potential, California North Coast (San Francisco)*

### Outside Air Ventilation

Classrooms and other school spaces must be ventilated to remove carbon dioxide from breathing, odors and other pollutants. The national consensus standard for outside air ventilation is ASHRAE Standard 62. This standard is the basis of requirements in Title 24 of the California Building Code (CBC). The CBC requires that outside air ventilation be provided through either natural ventilation or mechanical means.

If outside air is provided through natural ventilation, then all spaces within the room must be within 20 ft of a window, door or other ventilation opening, and the total area of ventilation openings must be greater than 5% of the floor area. For a typical 960 $ft^2$ (30 ft x 32 ft) classroom, the minimum free ventilation area must be at least 48 $ft^2$. The 20 ft rule would also require that ventilation openings be provided on two sides of the room; otherwise some portions of the classroom would be further than 20 ft from a window.

If outside are is provided through a mechanical system, then at least 15 cubic feet per minute (cfm) of outside are must be provided for each occupant. A typical classroom with 30 people requires a minimum of 15 x 30 or 450 cfm per occupant. However, the actual code minimum ventilation rate for a typical classroom is 360 cfm.[25] Other spaces in schools require differing levels of outside air ventilation, but are generally based on the expected occupant density of the space and the recommended ventilation rate of 15 cfm/occupant.

The number of occupants is highly variable in some school spaces such as gyms, auditoriums and multipurpose spaces. It may be desirable to vary the quantity of outside air ventilation in these spaces in response to the number of occupants. One technique for doing this is to install carbon dioxide ($CO_2$) sensors that measure concentrations and vary the volume of outside air accordingly. If an auditorium fills up for school assembly, then $CO_2$ concentrations will increase, a signal will be provided to the HVAC system and outside air volumes will be increased accordingly. This type of control can both save energy and improve indoor air quality.

The CBC not only specifies the minimum volume of outside air that needs to be provided to spaces, it also requires that this amount of air be provided during all hours when the spaces are normally occupied. Systems must also be designed to provide at least 3 air changes per hour or the required ventilation rate indicated above for the hour prior to normal occupancy of the building. The purpose of this requirement is to flush out building related contaminants that may have built up overnight while the system was shut down.

Outside air intake dampers must be carefully located to avoid pollution from sources such as parking lots or adjacent roadways. Patterns of air movement around buildings can be quite complex and dynamic. If there are major sources of pollution nearby, then designers are advised to build scale models and test them in wind tunnels.

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[25] Title 24 specifies 15 cfm per person and sets the occupant density at one half the code-specified occupant density for fire egress, which is 20 $ft^2$/occupant. This works out to 24 occupants for a typical 960 $ft^2$ classroom [(960 $ft^2$ / 20 $ft^2$/occupant)/2], and 24 occupants times 15 cfm per occupant is 360 cfm of outside air ventilation per classroom.

Indoor air quality is also affected by the selection of interior finishes and materials. These issues are discussed in the Interior Surfaces and Furnishings chapter. The design of air distribution ducts and fan systems can also have a significant effect on indoor air quality. Exposed fiberglass and other porous or flaking materials should not be used on the interior of ducts, unless they are encapsulated. In some applications ultraviolet (UV) lamps should be considered to kill bacteria and mold that might grow in ductwork.

## Load Calculations

Sizing HVAC systems in schools is critical to both energy efficiency and cost effectiveness. The compressors in oversized packaged air conditioners cycle frequently and overall efficiency drops significantly with each cycle. Cycling also reduces the efficiency of boilers, furnaces, heat pumps and many other types of equipment. Properly sized equipment reduces cycling and helps maintain efficient operation. Smaller equipment is also less costly and can reduce initial construction costs.

There are many computer programs and calculation methodologies that can be used for load calculations; Title 24 of the California Building Code has requirements on the types of load calculation methods that can be used, and the assumptions to be used in the analysis. The code also requires that equipment be selected that is no larger than necessary to satisfy the calculated load. However, there are a number of important exceptions to this requirement. For instance, if you want to use a particular manufacturer's product line, you can choose the smallest unit available within that product line, even though it may be larger than required. You can also use larger equipment if you can show that it does not increase energy use. This may be the case for oversized fans with variable speed control and other equipment that "unloads" intelligently. There are also exceptions for redundant units and multiple units that are sequenced to come on only as needed.

Title 24 requires that a procedure be used that is consistent with the 1993 *ASHRAE Handbook – Fundamentals*. Indoor design conditions must be consistent with ASHRAE Standard 55. Cooling systems must be designed for outdoor conditions that are exceeded for only 0.5% of the time. Exterior conditions for heating are also specified. Assumptions on outside air ventilation, occupant loads, envelope loads and lighting loads must be based on a building that complies with the CBC. Internal loads may be ignored for heating calculations since the school may be unoccupied with lights and equipment off when it is being warmed up in the morning. The calculated cooling loads may be increased by 33% and heating loads may be increased by 11% to account for warm-up loads, cool-down loads, and safety factors.

While many of the requirements for load calculations are specified in the CBC, much is left to the judgment of the mechanical engineer. The engineer should be careful to make choices and assumptions that are realistic and appropriate for each school design.

### Applicable Codes

The requirements of the CBC related to outside air ventilation and system sizing (load calculations) are described in the section above. In addition, the CBC has many other requirements that affect the selection and design of school's HVAC systems. Some of the requirements are highlighted here:

- Most equipment must meet minimum energy efficiency requirements. Air conditioner efficiency is expressed in terms of a minimum energy efficiency ratio (EER), while gas-fired heating equipment efficiency is expressed in terms of an annual fuel utilization efficiency (AFUE). Water heater efficiency is expressed in terms of an energy factor (EF).
- Systems that reheat or re-cool air are prohibited. This includes constant volume reheat systems and multi-zone system. Variable air volume (VAV) systems with reheat are permitted as long as air volume is reduced to the minimum before reheating occurs.
- Pipes and ducts must be insulated and sealed.
- Appropriate HVAC controls must be installed. Every classroom or other thermal zone must have its own thermostat to control the supply of heating and cooling to the space. Systems must also have a means to automatically shut them off during off hours. A time clock would be needed with at least two programmable schedules (one for a school day and one for a non-school day).
- Large systems (more than about 6 tons and more than 2,500 cfm) require that economizers be installed. Economizers are available and recommended for smaller systems as well as long as they are maintained and operated correctly.
- Large fan systems (25 hp or larger) have a maximum fan power limit of 0.8 W/cfm for constant volume systems and 1.25 W/cfm for variable volume systems.
- There are restrictions on the use of electric resistance heating systems, when other alternatives are available.

### Environmental Considerations

In terms of environmental performance, the HVAC system primarily affects energy efficiency and enhanced indoor environmental quality. Other environmental considerations are relevant, however, such as efficient use of materials, water conservation, and avoidance of ozone-depleting refrigerants. The following specific measures can be used to reduce the environmental impact of HVAC systems.

- A well-designed building will reduce the requirements for distribution of heat and cooled air. In addition to energy savings, this results in significantly less material used.
- A well-designed HVAC system provides easy access for cleaning and repair, reducing significantly a barrier to good indoor air quality.
- Selection of equipment and materials play a part as well.[26] Strategies and considerations include:
    - ○ Specifying low-toxic mastic to seal ducts.

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[26] For specific product recommendations, see *GreenSpec: The Environmental Building News Product Directory and Guideline Specifications*, http://www.buildinggreen.com, and OIKOS's Redi Guide (Resources for Environmental Design Index), available from Iris Communications, (800) 346-0104, http://www.oikos.com.

- Selecting durable equipment that can be easily refurbished.
- Avoiding equipment that relies on CFCs or HCFCs or relies on maintenance procedures that allow the ozone-depleting gases to escape.
- Consider alternatives to cooling towers and evaporative equipment, which use significant amounts of water.
- Metal components of HVAC systems can be recycled. In addition, metal components of HVAC equipment typically include recycled content, although data is not readily available as to the amount.
- Powder finishes used on equipment may pose a problem during manufacture, but information about these finishes is not readily available.

### Commissioning

Commissioning is the process of ensuring that the intent of the project program is properly reflected in the design and that the design intent is properly executed during construction and operation. Commissioning tasks start at the very beginning and continue throughout the project even into the occupancy period. Experience has shown that many energy efficient designs do not achieve intended savings without the oversight and testing included in a commissioning process.

For larger facilities, the project manager should consider including an independent commissioning agent in the early planning process. A commissioning plan should be developed during schematic design and updated at each project phase. Typical elements of a commissioning process include:

- Commissioning plan development
- Documentation of design intent
- Design review
- Submittals review
- Inspections and system functional testing
- Enhanced operating and maintenance documentation
- Post occupancy testing

For small schools with relatively simple mechanical systems, a detailed commissioning process may not be feasible. However, some form of performance assurance plan is essential to be sure that systems are operating properly and at peak efficiency before occupancy.

Specific commissioning issues are discussed in each of the guidelines below. A number of sample commissioning plans and guidelines are also available. A good source to start is Portland Energy Conservation Inc. at http://www.peci.org.

### Design Tools

In addition to general energy simulation programs, there are many tools useful for optimizing mechanical design. Most commonly used are heating and cooling load calculation programs that are widely available from equipment manufacturers and commercial vendors. Other programs integrate with CAD software and aid the design of piping and duct systems. Many of these tools also have cost estimating capability, which is very helpful in design optimization.

Computational fluid dynamics software can help in studies of natural and mechanical ventilation and is very useful in creative integration of mechanical and architectural design. However, this type of analysis is currently expensive.

### Controls

As computerized building systems become more advanced, schools are becoming more complicated. HVAC, lighting, water heating, signal/communication wiring, and other systems need to be operated and controlled efficiently and effectively. With integrated design, the effective control of one system may depend on how another system is being operated. Building management systems offer the potential for integrated control of HVAC, lighting, outside air ventilation, natural ventilation, building security and water heating systems. Energy can be saved through efficient control and by turning systems off when they are not needed. Building management systems can also provide information for students and faculty to understand how the building is working and how much energy it is using.

### System Selection

Figure 20 illustrates a few important questions that help narrow the choice of HVAC system for each space. This decision tree leads to one of several categories of system types. There are three main questions:

1. Can natural ventilation meet all reasonable cooling needs? For many locations in California this is possible, especially with careful attention to architectural design. If cooling is unnecessary, then a number of heating-only options exist.
2. Can outdoor air ventilation be provided naturally or is mechanical ventilation required? This affects the system choice regardless of whether it is heating only or heating and cooling. If fans are not required for ventilation, then the system can be designed to be left off for much of the year, saving fan energy.
3. If cooling is required, can an efficient evaporative cooling system be used? If not, compressor cooling, either with a direct expansion (DX) or chilled water system is required.

There are, of course, many other considerations in system selection. This chapter provides guidelines for most of the common HVAC system types used in California schools. The choice of optimal system type for a specific school is a complex decision based on many factors. Many tradeoffs are involved, especially price versus performance. Other important considerations are:

- noise and vibration
- indoor air quality ventilation performance

- thermal comfort performance
- operating costs and energy efficiency
- maintenance costs and needs
- space requirements (in the classroom, on the roof or in mechanical rooms)
- durability and longevity
- the ability to provide individual control for classrooms and other spaces
- the type of refrigerant used and its ozone-depleting potential

Table 23 compares system types using these criteria and others. More information regarding the applicability of each system type is discussed in the individual guidelines.

Phasing of construction projects also influences the decision between central systems and distributed systems. If a large facility is to be constructed in several phases, then it may be difficult to afford the upfront investment in the central plant option.

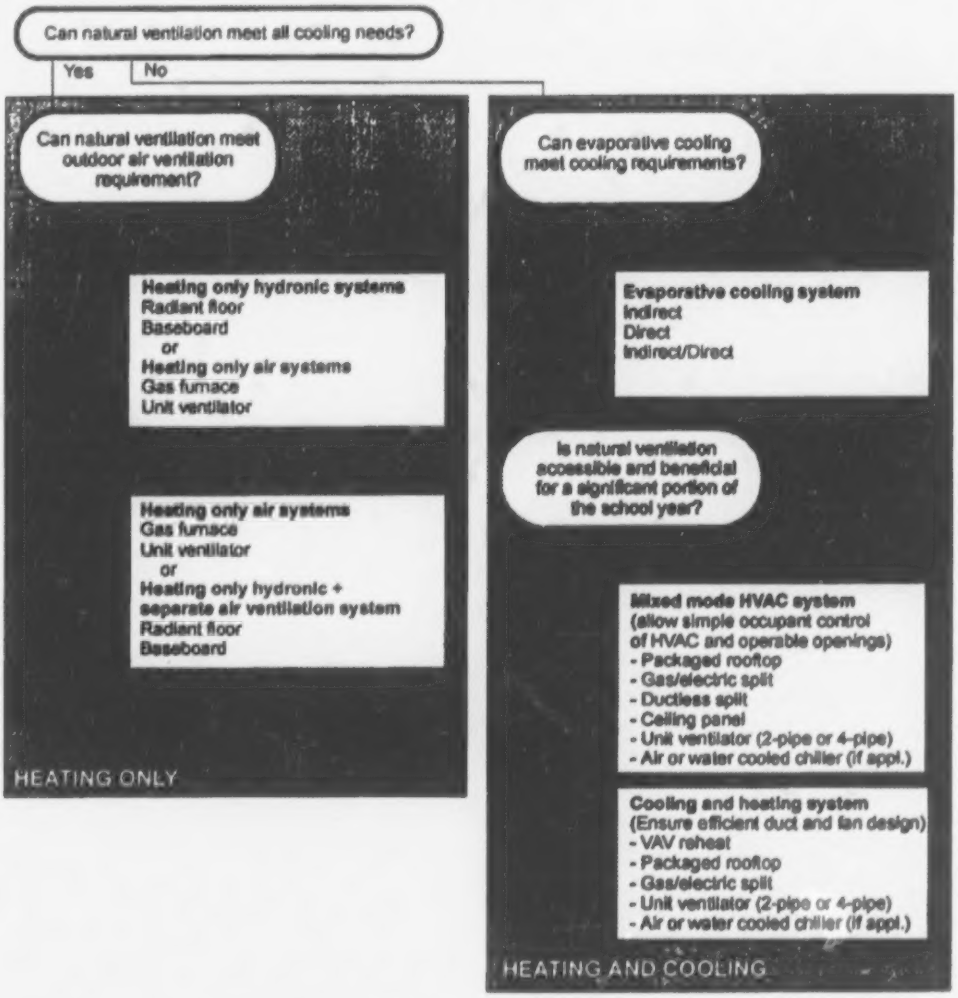
Can natural ventilation meet all cooling needs?
Yes
No
Can natural ventilation meet outdoor air ventilation requirement?
Heating only hydronic systems
Radiant floor
Baseboard
or
Heating only air systems
Gas furnace
Unit ventilator
Heating only air systems
Gas furnace
Unit ventilator
or
Heating only hydronic + separate air ventilation system
Radiant floor
Baseboard
HEATING ONLY
Can evaporative cooling meet cooling requirements?
Evaporative cooling system
Indirect
Direct
Indirect/Direct
Is natural ventilation accessible and beneficial for a significant portion of the school year?
Mixed mode HVAC system
(allow simple occupant control of HVAC and operable openings)
- Packaged rooftop
- Gas/electric split
- Ductless split
- Ceiling panel
- Unit ventilator (2-pipe or 4-pipe)
- Air or water cooled chiller (if appl.)
Cooling and heating system
(Ensure efficient duct and fan design)
- VAV reheat
- Packaged rooftop
- Gas/electric split
- Unit ventilator (2-pipe or 4-pipe)
- Air or water cooled chiller (if appl.)
HEATING AND COOLING

*Figure 20 – HVAC System Selection Decision Tree*

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| Selection Criteria | | Gas/Electric Split system | Rooftop packaged system | Displacement ventilation | Ceiling Panels | Unit ventilator (4-pipe) | Unit ventilator (2-pipe) | Ductless Split System | Evaporative cooler | VAV/reheat. | Radiant floor | Baseboards | Gas-Fired Radiant system | Chiller – Water Cooled | Chiller – Air Cooled |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| First Cost | | ◒ | ● | ○ | ○ | ○ | ◒ | ◒ | ◒ | ◒ | ○ | ◒ | ◒ | ○ | ◒ |
| Maintenance Cost | | ◒ | ◒ | ◒ | ◒ | ○ | ○ | ◒ | ● | ◒ | ◒ | ◒ | ◒ | ◒ | ◒ |
| Cooling Effectiveness | | ◒ | ◒ | ● | ● | ◒ | ◒ | ○ | ◒ | ● | na | na | na | ● | ● |
| Heating Effectiveness | | ◒ | ◒ | ○ | ○ | ◒ | ○ | ○ | na | ◒ | ● | ● | ● | na | na |
| Energy Operating Cost | | ◒ | ○ | ● | ● | ◒ | ◒ | ◒ | ● | ◒ | ● | ◒ | ● | ● | ◒ |
| Durability | | ◒ | ◒ | ◒ | ● | ◒ | ◒ | ◒ | ◒ | ● | ● | ● | ◒ | ● | ◒ |
| Life-cycle Cost | | ◒ | ◒ | ● | ◒ | ○ | ○ | ◒ | ● | ◒ | ◒ | ◒ | ◒ | ● | ◒ |
| Noise (Acoustic Environment) | | ◒ | ◒ | ● | ● | ○ | ○ | ○ | ◒ | ◒ | ● | ● | ● | ◒ | ◒ |
| Roof Space Required | | ● | ○ | ◒ | ● | ● | ● | ● | ○ | ○ | ● | ● | ● | na | na |
| Water Consumption | | ● | ● | ● | ● | ● | ● | ● | ○ | ● | ● | ● | ● | ◒ | ● |
| Classroom Control | | ● | ● | ● | ◒ | ● | ● | ● | ● | ● | ○ | ◒ | ● | na | na |
| Multi-zone Capability | | ○ | ○ | ○ | ◒ | ○ | ○ | ○ | ○ | ● | ◒ | ◒ | ◒ | na | na |
| Ozone Depletion | | ○ | ○ | ◒ | ◒ | ◒ | ◒ | ○ | ● | ◒ | ◒ | ◒ | ◒ | ◒ | ◒ |
| Outside Air Ventilation | | ◒ | ◒ | ● | ○ | ◒ | ◒ | ○ | ● | ◒ | ○ | ○ | ○ | na | na |
| Thermal Comfort | | ◒ | ◒ | ● | ● | ○ | ○ | ○ | ◒ | ● | ● | ◒ | ◒ | na | na |
| Natural Ventilation (Mixed Mode Method) | Compatibility (poor/fair/good) | ◒ | ◒ | ◒ | ● | ◒ | ◒ | ◒ | ◒ | ○ | ● | ◒ | ● | na | na |
| | Change-Over (yes/no) | ● | ● | ● | ○ | ● | ● | ● | ● | ● | ○ | ○ | ○ | na | na |
| | Concurrent (yes/no) | ○ | ○ | ○ | ● | ○ | ○ | ○ | ○ | ○ | ● | ● | ● | na | na |
| Indoor Air Quality | | ◒ | ◒ | ● | ● | ◒ | ◒ | ◒ | ◒ | ◒ | ● | ● | ● | na | na |

Legend:

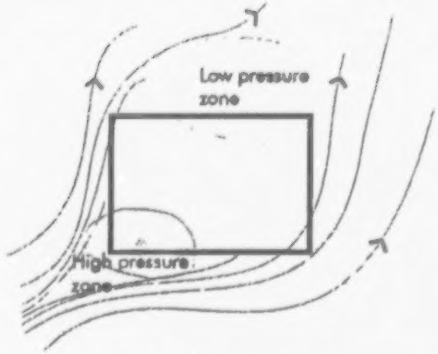
- ● Better than average (better performance or lower cost)
- ◒ Average
- ○ Worse than average (lower performance or higher cost)

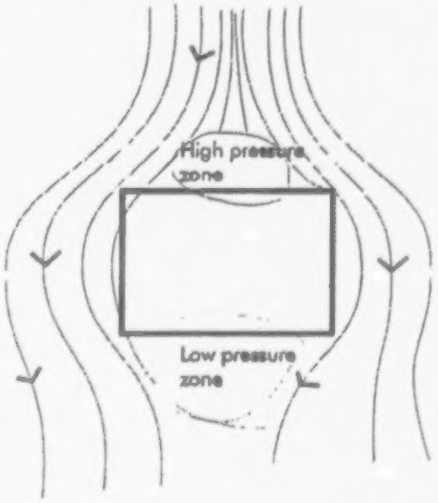
| Selection Criteria | | Gas/Electric Split system | Rooftop packaged system | Displacement ventilation | Ceiling Panels | Unit ventilator (4-pipe) | Unit ventilator (2-pipe) | Ductless Split System | Evaporative cooler | VAV/reheat | Radiant floor | Baseboards | Gas-Fired Radiant system |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Spaces Applicability (black, gray or clear) | Classrooms | ● | ◒ | ● | ● | ◒ | ◒ | ○ | ◒ | ◒ | ● | ◒ | ○ |
| | Library | ◒ | ◒ | ◒ | ○ | ○ | ○ | ○ | ◒ | ● | ◒ | ◒ | ○ |
| | Multi-purpose | ◒ | ◒ | ◒ | ○ | ○ | ○ | ○ | ● | ◒ | ◒ | ◒ | ● |
| | Gym | ◒ | ◒ | ○ | ○ | ○ | ○ | ○ | ● | ◒ | ◒ | ○ | ● |
| | Corridors | ◒ | ◒ | ○ | ○ | ○ | ○ | ○ | ● | ◒ | ◒ | ◒ | ○ |
| | Admin | ◒ | ◒ | ● | ● | ○ | ○ | ◒ | ● | ● | ◒ | ● | ○ |
| | Toilets | ◒ | ◒ | ○ | ◒ | ○ | ○ | ◒ | ◒ | ◒ | ◒ | ◒ | ○ |
| | Other | ◒ | ◒ | ◒ | ◒ | ◒ | ◒ | ◒ | ◒ | ◒ | ◒ | ◒ | ◒ |
| Climate Applicability (black, gray or clear) | South Coast | ◒ | ◒ | ● | ● | ◒ | ○ | ◒ | ● | ● | ◒ | ◒ | ◒ |
| | North Coast | ◒ | ◒ | ◒ | ◒ | ◒ | ◒ | ◒ | ◒ | ● | ● | ● | ● |
| | Central Valley | ◒ | ◒ | ● | ● | ◒ | ○ | ◒ | ◒ | ● | ● | ● | ● |
| | Desert | ◒ | ◒ | ● | ● | ◒ | ○ | ◒ | ● | ● | ◒ | ◒ | ◒ |
| | Mountains | ◒ | ◒ | ◒ | ◒ | ◒ | ◒ | ◒ | ● | ● | ● | ● | ● |
| Possible Cooling Sources | DX | ● | ● | ◒ | ○ | ◒ | ◒ | ● | ○ | ● | na | na | na |
| | CHW | ○ | ○ | ● | ● | ● | ● | ○ | ○ | ● | na | na | na |
| Possible Heating Sources | HP | ○ | ● | ● | ○ | ◒ | ◒ | ● | ○ | ○ | ○ | ○ | ○ |
| | HW | ○ | ◒ | ● | ● | ● | ● | ○ | ◒ | ● | ● | ● | ○ |
| | Furnace | ● | ● | ● | ○ | ○ | ○ | ○ | ◒ | ● | ○ | ○ | ○ |
| Optional Energy Efficient Features | Air Economizer | ◒ | ● | ● | ○ | ● | ● | ◒ | ● | ● | ○ | ○ | ○ |
| | Evaporative Precooler | ● | ● | ● | ○ | ○ | ○ | ○ | ○ | ● | ○ | ○ | ○ |
| | Variable Speed Fan | ◒ | ◒ | ◒ | ○ | ◒ | ◒ | ◒ | ● | ● | ○ | ○ | ○ |
| | High Efficiency Motors | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ○ |

Legend:

● Better than average (better performance or lower cost)
◒ Average
○ Worse than average (lower performance or higher cost)

# Guideline TC1: Cross Ventilation





## Recommendation

Provide equal area of operable openings on the windward and leeward side. Ensure that the windward side is well shaded to provide cool air intake. Locate the openings on the windward side at the occupied level.

## Description

Wind driven ventilation is one of two methods of providing natural ventilation. All natural ventilation strategies rely on the movement of air through space to equalize pressure. When wind blows against a barrier, it is deflected around and above the barrier (in this case, a building). The air pressure on the windward side rises above atmospheric pressure (called the pressure zone). The pressure on the leeward side drops (suction zone), creating pressure stratification across the building. To equalize pressure, outdoor air will enter through available openings on the windward side and eventually be exhausted through the leeward side.

Pressure is not uniformly distributed over the entire windward face, but diminishes outwards from the pressure zone. The pressure difference between any two points on the building envelope will determine the potential for ventilation if openings were provided at these two points. The airflow is directly proportional to the effective area of inlet openings, wind speed, and wind direction.

## Applicability

| Applicable Spaces | | | Climates | | When to Consider | |
|---|---|---|---|---|---|---|
| Classrooms | ■ | ■ | South Coast | ■ | Programming | ☐ |
| Library | ■ | ☐ | North Coast | ☐ | Schematic | ■ |
| Multi-Purpose / Cafeteria | ■ | ■ | Central Valley | ■ | Design Dev. | ■ |
| Gym | ■ | ☐ | Mountains | ☐ | Contract Docs. | ☐ |
| Corridors | ☐ | ■ | Desert | ■ | Construction | ☐ |
| Administration | ■ | | | | Commissioning | ☐ |
| Toilets | ☐ | | | | Operation | ■ |
| Other | ■ | | | | | |

Cross ventilation is a very effective strategy for heat removal and providing airflow in mild climates. In coastal climates the need for a cooling system may be eliminated by a carefully designed natural ventilation system. In most other climates it can alter interior conditions only modestly. Hybrid systems work best in such situations. In humid climates, it cannot replace the moisture removing capabilities of air-conditioning (although desiccant systems that remove moisture from the space can be used for more effective natural ventilation). Introducing humid air (even if it's relatively cool) into a space will add a substantial load on the cooling system. However, even extreme climates experience moderate conditions during spring and fall, and natural ventilation should be designed to take full advantage of these conditions.

This strategy relies heavily on two parameters that may change continuously- availability of wind and wind direction. Consequently, it is a somewhat unreliable source for thermal comfort. Spaces like computer rooms and laboratories that need strict maintenance of indoor temperature and humidity, should definitely

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use hybrid systems for both cooling and ventilation. Introducing natural ventilation in a building may cause increased levels of dirt, dust, and noise. This could also be a serious limitation for certain types of spaces.

Cross ventilation has to be an integral part of the design schematic and design development phases. An effective natural ventilation design starts with limiting space sizes to facilitate inward flow of air from one face and outward flow from the other- architectural elements can be used to harness prevailing winds. This may alter building aesthetics and needs to be addressed early in the design phase.

### Applicable Codes

'Section 121-Requirements for Ventilation' of T24 apply to spaces that are ventilated naturally (without mechanical means) only. These requirements include:

- The total area of the openings should be at least 5% of the total floor area (based on classroom dimensions of 30'-0"x32'-0"x9'-6", a minimum openable area of 48'-0" should be provided for each classroom).
- All spaces should be within 20'-0" of an operable opening in the wall or roof.
- All openings provided for natural ventilation should be readily accessible to occupants of the space at all times when the space is occupied.
- All naturally ventilated spaces should have direct outdoor air flow from openings in the wall or roof. This air flow should remain unobstructed by walls or doors.

Codes related to fenestration performance and maximum allowable window area are also relevant:

- Maximum allowable Window Wall Ratio limits the area of openings to 40% of the wall area. The code also specifies minimum performance levels for fenestrations. See Daylighting Guidelines for more information on performance levels for glazing.

### Integrated Design Implications

- **Design Phase.** Cross ventilation can (or should) very strongly influence building aesthetics and site planning. Natural ventilation codes will dictate space widths and minimum opening sizes. To maximize the effectiveness of openings, the long façade of a building should be perpendicular to the prevailing wind direction. Narrow and woven plans with more surfaces exposed to the outside will work better than bulky plans with concentrated volumes. Singly loaded corridors will provide better air flow than doubly loaded ones. An open building plan with plenty of surface area exposed to the outside will work well for cross ventilation. Architectural elements like fins, wing walls, parapets, and balconies will enhance wind speeds and should be an integral part of cross ventilation design.
- **Thermal Mass.** Cross-ventilation should be combined with thermal mass to take advantage of large diurnal temperature swings. Mass walls can act as heat reservoirs, absorbing heat through the day and dissipating it at night. At nighttime, natural ventilation can be used to increase the quantum of dissipated heat as well as to accelerate the process of dissipation (see section on Building Envelope for details). This will reduce the load on the cooling system by pre-cooling the building. A large diurnal temperature swing (as in desert areas) will ensure that the building is more effectively 'flushed'.
- **Integration with Daylighting and View Windows.** The apertures for cross ventilation will also serve as view windows and luminaires for side lighting. All architectural elements intended to enhance one strategy should also work for the other. Orientation that works for ventilation (openings on the windward side) may not be the ideal direction for bringing in daylight. West orientation for windows will increase heat gain and cause glare, but this may be the best orientation for bringing in outside air in the coastal areas. Prioritize the needs of the space based on function and climate. For instance, benefits of daylighting in a cold climate outweigh those of cross ventilation- therefore orient the building based on daylighting considerations.
- **Integration with HVAC.** Natural ventilation may be intended to replace air conditioning entirely or, as is more often the case, to coexist with mechanical systems in a 'hybrid mode'. Also, natural ventilation may occur in 'change-over' (windows are shut when mechanical system is on) or 'concurrent' modes.

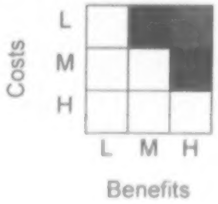
Fewer systems are compatible with the concurrent mode. These factors need to be carefully considered before selecting a system (for more information on system selection see the HVAC Overview).

### Costs

Low - moderate. Buildings that use natural ventilation may have higher initial costs, due to the higher cost of operable windows. Operable windows typically cost 5%-10% more than fixed glazing. Based on average installed cost for metal frame, double-glazed, fixed windows of $\$20/ft^2$-$\$30/ft^2$, the operable window should cost \$48-\$72 more per classroom for buildings that meet their ventilation needs through natural ventilated only (based on code prescribed minimum area of operable glazing per classroom). For 'hybrid' buildings, the cost will be more modest because the operable window area can be less than the code prescribed minimum (5% of floor area). In buildings where natural ventilation is designed to occur concurrently, the initial costs may be higher due to limitations in system selection.

### Benefits

Moderate - high. This varies significantly depending on climatic conditions and natural ventilation design.



- In a moderate climate like that of the north coast, wind-driven ventilation can meet the cooling loads most of the time. In such climates the simple payback period will vary between 8-12 years. At times, a good natural ventilation design may completely eliminate the need for a cooling system. This will result in huge savings that will offset the cost of installing operable windows thereby lowering the simple payback period to 1-4 years.
- Buildings located in harsher climates will use 'mixed-mode' systems. In such climates, natural ventilation may have limited application resulting in higher payback periods of 12-15 years.
- Cross ventilation alleviates odors and quickly exhausts contaminants from a space.
- Increased airflow in a space results in higher thermal comfort levels and increased productivity.
- Operable openings at the occupied level instill the occupants with a sense of individual control over the indoor environment.
- An intangible benefit of natural ventilation is that it establishes a connection with the outdoors (both visual and tactile), weather patterns, and seasonal changes. This results in higher tolerances for variations in temperature and humidity levels.
- Natural ventilation systems are simple to install and require little maintenance.

### Design Tools

Opening areas may be derived from simple using spreadsheet-based calculations. These estimates use approximation techniques but are good numbers to start with. The following algorithm shows the rate of wind-induced airflow through inlet openings:

$$Q = C_4 C_v AV$$

where,

$Q$ =airflow rate, cfm

$C_v$ =effectiveness of openings ($C_v$ is assumed to be 0.5-0.6 for perpendicular winds and 0.25 to 0.35 for diagonal winds)

$A$ =free area of inlet openings

$V$ =wind speed, mph

$C_4$ =unit conversion factor= 88.0

The following algorithm calculates the required airflow rate for removal of a given amount of heat from space (see section on Load Calculations for estimating the amount of heat to be removed):

$$Q = \frac{60q}{c_p \rho (t_i - t_o)}$$

where,

$Q$ =airflow rate required to remove heat, cfm

$q$ =rate of heat removal, Btu/h

$C_p$ =specific heat of air Btu/lb°F (about 0.24)

$\rho$ =air density, $lb_m/ft^3$ (about 0.075)

$t_i$-$t_o$ =indoor-outdoor temperature difference, °F

Many computer software are available for predicting ventilation patterns. Some that use the 'zonal' method may be used to predict ventilation rate (mechanical and natural), magnitude and direction of air flow through openings, air infiltration rates as a function of climate and building air leakage, pattern of air flow between zones, internal room pressures, pollutant concentration, and back drafting and cross contamination risks. These models take the form of a flow network in which zones or rooms of differing pressure are interconnected by a set of flow paths. This network is approximated by a series of equations that represent the flow characteristics of each opening and the forces driving the air flow process. Widely available codes include BREEZE and COMIS.

A Computational Fluid Dynamics (CFD) program is a more accurate and complex tool for modeling airflow through a space based on pressure and temperature differentials. These programs can simulate and predict room airflow, airflow in large enclosures (atria, shopping malls, airports, exhibitions centers etc.), air change efficiency, pollutant removal effectiveness, temperature distribution, air velocity distribution, turbulence distribution, pressure distribution, and airflow around buildings. Fluent, Inc. is the largest provider of CFD code. FLUENT is a sophisticated analysis technique that can, among other things, model and/or predict fluid flow behavior, transfer of heat, and behavior of mass. Flomerics authors the software FLOVENT, designed to calculate airflow, heat transfer, and contamination distribution for built environments. This software is particularly geared towards ventilation calculations including natural and forced convection currents. It also accurately calculates air density as a function of temperature and predicts the resulting buoyancy forces that can give rise to important thermal stratification effects. Important outputs from FLOVENT are user variables such as the comfort indices of Predicted Mean Vote (PMV), Percentage of People Dissatisfied (PPD), Mean Radiant Temperature (MRT), Dry Resultant Temperature and Percentage Saturation, including a visualization of their variation through space. A summary of minimum, maximum, mean and standard deviation for all calculated variables is also available.

### Design Details

- Orient the building to maximize surface exposure to prevailing winds.
- Provide the inlets on the windward side (pressure zone) and the outlets on the leeward side (suction zone). Use architectural features like wing walls and parapets to create positive and negative pressure areas to induce cross ventilation. Air speed inside a space varies significantly depending on the location of openings (see table below). As far as possible, provide openings on opposite walls. Using singly loaded corridors will facilitate provision of openings on opposite walls. Limit room widths to 15'-20' if openings cannot be provided on two walls. Windows placed on adjacent walls also perform very due to the wall-jet phenomenon wherein the inflowing air moves along the nearest wall surfaces. This positioning should be limited to smaller spaces (less than 15'x15').

*Table TC-24— Average indoor air velocity as a percentage of the exterior wind velocity for wind direction perpendicular to and 45° to the opening*

| Window height as a fraction of wall height | 1/3 | 1/3 | 1/3 |
|---|---|---|---|
| Window width as a fraction of wall height | 1/3 | 2/3 | 3/3 |
| Single opening | 12-14% | 13-17% | 16-23% |
| Two openings on same wall | - | 22% | 23% |
| Two openings in adjacent walls | 37-45% | - | - |
| Two openings on opposite walls | 35-42% | 37-51% | 46-65% |

*Source: Givoni, Baruch;* Man, Climate, and Architecture, *London: Applied Science, 1976.*

- A free ventilation area of 1.5%-2% (of the floor area) will meet the ventilation requirements. This is the recommended minimum area for operable windows only. Daylighting considerations will require a larger window area. Also- if the space is solely dependent on natural ventilation then code requirements will set the minimum operable window area to 5% of the floor area. Although this area will meet the ventilation requirements of a space during mild climatic conditions, larger window areas should be provided for occupant cooling through increased air movement. For cooling purposes provide 5%-8% of the floor area as free ventilation area. Equal inlet and outlet areas maximize airflow whereas outlets that are 2%-5% larger than inlets produce higher air velocities.The inlet location effects airflow patterns far more significantly than outlet location. Inlet location should be a higher priority (if faced with a choice) as a high inlet will direct air towards the ceiling and will almost bypass the occupied level. Locate inlets at a low or medium height.For natural ventilation to function properly, solar gains should be minimized. Direct sunlight penetrating into the space during periods of natural ventilation may make it difficult or impossible to achieve comfortable conditions with natural ventilation alone. Use shading devices to like overhangs, awnings, and fins to control solar gains.
- The incoming air may be cooled through good site planning, landscaping and planting strategies. If a water body is planned for the site, place it on the windward side to pre-cool the incoming air through evaporative cooling. Planting tall deciduous trees on the windward side will lower the temperature of the inflow and shade the openings.
- Provide windows with shutters that can be opened or shut in increments. This allows the occupants to vary the inlet and outlet areas according to seasonal variations.
- Use features like overhangs, awning windows, eaves, and porches to protect the openings from rain. Awning windows work very well for cross ventilation because they provide more airflow than double hung windows (for the same glazed area) and also provide protection from rain. Casement windows provide maximum airflow in both perpendicular and oblique wind conditions. Ensure that vents and windows are accessible and easy to use. Avoid blocking windows with exterior objects such as shrubs and fences, but do not eliminate shading.
- Provide inlets for cross-ventilation openings at the occupied level. Stagger the outlet openings both vertically and horizontally by a few feet to achieve longer air paths. Concentrate ventilation openings in spaces most likely to require cooling.
- Use overhangs, porches, and eaves to protect windows and vents from rain. This extends the amount of time that natural ventilation can be used.
- Ensure that openings can be tightly sealed in winter or when using an air conditioner.
- HVAC systems should be designed to work in harmony with natural ventilation. The objective of a concurrent natural ventilation system is to meet the outside air requirement using the least possible opening area. The objective of a change-over natural ventilation system is to meet the outside air requirement as well as provide cooling. The HVAC and natural ventilation system are mutually dependent. See Overview for a detailed discussion.

## Operation and Maintenance Issues

This strategy is largely dependent on manual operation for its success. Automated operation may make sense for very large commercial buildings, but not for schools.

- Encourage students and teachers to open/close openings regularly.
- The mechanisms for operable inlets and outlets should be well maintained and clean.
- Periodically clean windowsills, panes, fins, and louvers to ensure healthy air intake for the space.
- Assign responsibility of ensuring that openings are shut during the hours of operation of the mechanical system. Also ensure adequate opening area is available for nighttime ventilation in hot dry climates.

## Commissioning

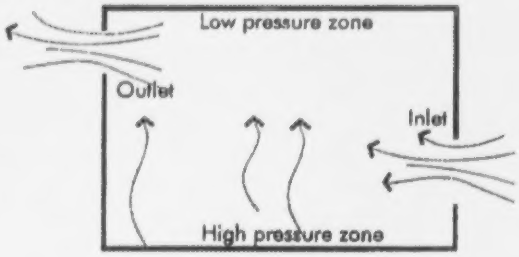
None.

## References / Additional Information

Passive Cooling by Jeffrey Cook (Ed.), MIT Press, Cambridge, USA, 1989.

Sun, Wind, and Light by G.Z. Brown, John Wiley & Sons, New York, 1986.

# Guideline TC2: Stack Ventilation



**Recommendation**

Use inlets and outlets of equal area and maximize the vertical distance between these two sets of apertures. Place inlets close to the floor or at the occupied level. Locate the outlets closer to the ceiling on the opposite wall. To facilitate varying summer and winter strategies, provide incrementally operable shutters.

| Applicable Spaces | | Climates | | When to Consider | |
|---|---|---|---|---|---|
| Classrooms | ■ | South Coast | ■ | Programming | ☐ |
| Library | ■ | North Coast | ☐ | Schematic | ■ |
| Multi-Purpose / Cafeteria | ■ | Central Valley | ■ | Design Dev. | ■ |
| Gym | ■ | Mountains | ☐ | Contract Docs. | ☐ |
| Corridors | ☐ | Desert | ■ | Construction | ☐ |
| Administration | ■ | | | Commissioning | ☐ |
| Toilets | ☐ | | | Operation | ■ |
| Other | ■ | | | | |

**Description**

Stack ventilation is one of two methods of providing natural ventilation. Stack ventilation utilizes the difference in air densities to provide air movement across a space. At least two ventilation apertures need to be provided- one closer to the floor and the other high in the space. Warmed by internal loads (people, lights, and equipment), the indoor air rises. This creates a vertical pressure gradient within the enclosed space. If an aperture is available near the ceiling, the warmer air at the upper levels will escape as the cool outside air is drawn in by the lower aperture. Higher indoor temperatures are essential for causing a pressure difference such that the upper openings act as the outlet and cool air intake is induced at the lower opening.

The airflow induced by thermal force is directly proportional to the inlet-outlet height differential, the effective area of the aperture, and the inside-outside temperature differential.

**Applicability**

Pressure differential driven natural ventilation is an effective strategy for meeting minimum airflow requirements, especially during winter, when the inside-outside temperature differential is at a maximum. It is also appropriate for providing cooling during mild weather conditions.

**Applicable Codes**

'Section 121-Requirements for Ventilation' of T24 apply to spaces that are ventilated naturally (without mechanical means) only. These requirements include:

- The total area of the openings should be at least 5% of the total floor area (based on classroom dimensions of 30'-0"x32'-0"x9'-6", a minimum openable area of 48'-0" should be provided for each classroom).
- All spaces should be within 20'-0" of an operable opening in the wall or roof.
- All openings provided for natural ventilation should be readily accessible to occupants of the space at all times when the space is occupied.
- All naturally ventilated spaces should have direct outdoor air flow from openings in the wall or roof. This air flow should remain unobstructed by walls or doors.

Codes related to fenestration performance and maximum allowable window area are also relevant:

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- Maximum allowable Window Wall Ratio limits the area of openings to 40% of the wall area. The code also specifies minimum performance levels for fenestrations. See Daylighting Guidelines for more information on performance levels for glazing.

## Integrated Design Implications

- **Design Phase.** Using the stack effect for ventilation requires an integrated design approach. Stack ventilation will affect building mass and aesthetics. Vertical airshafts for providing stack ventilation also need to be considered early in the design phase.
- **Thermal Mass.** Nighttime ventilation coupled with thermal mass is a very effective strategy for heat removal from space in hot dry climates. See Thermal Mass for details.
- **Integration with Daylighting and View Windows.** Apertures for stack ventilation need to be located close to the floor and ceiling for best results. The high apertures can couple as clerestories or side lighting luminaries. Benefits of daylighting and natural ventilation need to be considered in conjunction with each other to arrive at the ideal location and size for openings.
- **Integration with HVAC.** Stack ventilation will be used for meeting the outside air requirement in most climates other than hot-dry (where stack ventilation will also be used for nighttime cooling). Carefully integrating this strategy with HVAC system selection and operation will maximize its benefits. For details see the Overview section.

## Costs

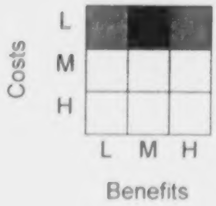
Low - moderate.

Stack ventilation may not add to overall costs significantly if integrated with view windows, high side lighting, and other daylighting strategies. However, an additional cost of $2/ft$^2$ may be associated with ensuring that all openings are operable. Adjustable frame intake louvers may cost up to $25/ft$^2$ (this includes installation costs). Additional cost of installing windows high in the space will range from $15-$30/ft$^2$.

## Benefits

Low -moderate.

This depends on largely on weather conditions (indoor-outdoor temperature differential) and the design of openings.



- In a moderate climate like that of the north coast, a combination of wind-driven and stack ventilation strategies can meet the cooling loads most of the time. In more extreme climates (with a large diurnal range of temperature), stack ventilation can operate in 'mixed-mode' systems and reduce the peak demand through nighttime flushing. This will result in lower utility bills and first costs. In such climates the simple payback period will be 8-12 years. For most other climates the simple payback period will be 10-14 years.
- Stack ventilation apertures can also double as side and high side lighting strategies.
- Stack ventilation effectively removes contaminants and pollutants from space.

## Design Tools

The airflow (cfm) required can be reasonably estimated using spreadsheet based calculations. The following algorithm defines the air flow as it varies with the area of openings, indoor temperature, outdoor temperature, and location of the inlet and outlet:

$$Q = 60C_DA\sqrt{2g\Delta H_{NPL}(T_i - T_o)/T_i}$$

Q =airflow rate, cfm

$C_D$ =discharge coefficient for opening

$\Delta H_{NPL}$ = height from mid-point of lower opening to NPL, ft

$T_i$ =indoor temperature, °R

$T_o$ =outdoor temperature, °R

Use this algorithm to estimate the aperture area for a particular hour of a day (with Q equal to 15 cfm).

A number of computer tools are available for simulating pressure driven airflow. Refer to Guideline TC1-Cross Ventilation for details.

### Design Details

- Provide equal inlet and outlet areas to maximize airflow. Airflow will be dictated by the smaller of the inlet and outlet areas.
- The width to height ratio of openings should be more than one as far as possible, i.e., orient openings horizontally.
- The free ventilation area of the inlet and outlet should be at least 1% of the total floor area of the room ($4.8ft^2$ each /classroom -based on 32' x 30' x 9'-6" classrooms). This is adequate to meet outdoor air requirements with perpendicular wind speeds as low as 2 MPH and low temperature differentials that occur during summer months. Uncomfortable winter conditions may be avoided by lowering the air intake of these openings during winter or completely shutting some of these openings. For extreme climates all the available operable openings may remain open only for limited periods.
- Allow for at least a 5' ft c/c height difference between the inlet and the outlet. Increasing the height differential further will produce better airflow.
- Use stairwells or other continuous vertical elements as stack wells by providing adequate apertures. Such spaces may be used to ventilate adjacent spaces because of their ability to displace large volumes of air (because of greater stack height).
- Carefully control and minimize solar gains. For details see Guidelines TC1 – Cross Ventilation.
- Combine stack ventilation with cross ventilation elements. Set the inlet openings for cross ventilation lower in the wall so that they can double as inlets for stack ventilation.
- Use louvers on inlets to channel air intake. Use architectural features like wind towers and wind channels to effectively exhaust the hot indoor air.
- HVAC systems should be designed to work in harmony with stack ventilation (see Overview section for a discussion).

### Operation and Maintenance Issues

This strategy is largely dependent on manual operation for its success

- Openings should be appropriately operated according to indoor-outdoor temperature differentials.
- The mechanisms for operable inlets and outlets should be well maintained and clean.
- Windowsills, fins, and louvers should be periodically cleaned to ensure healthy air intake for the space.
- Assign responsibility of ensuring that openings remain shut during the hours of operation of the mechanical system unless the ventilation is designed to work concurrently.
- Ensure that adequate opening area is available for nighttime ventilation in hot dry climates.

### Commissioning

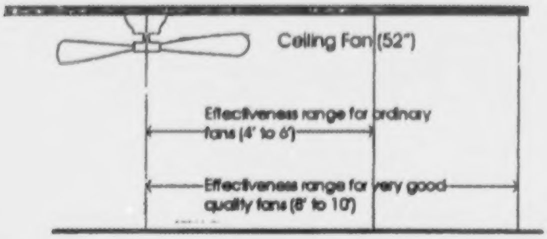
None.

## References / Additional Information

Passive Cooling by Jeffrey Cook (Ed.), MIT Press, Cambridge, USA, 1989.

Sun, Wind, and Light by G.Z. Brown, John Wiley & Sons, New York, 1986.

## Guideline TC3: Ceiling Fans


Ceiling Fan (52")
Effectiveness range for ordinary fans (4' to 6')
Effectiveness range for very good quality fans (8' to 10')

| Applicable Spaces | | Climates | | When to Consider | |
|---|---|---|---|---|---|
| Classrooms | ■ | South Coast | ■ | Programming | ☐ |
| Library | ■ | North Coast | ■ | Schematic | ☐ |
| Multi-Purpose / Cafeteria | ■ | Central Valley | ■ | Design Dev. | ■ |
| Gym | ☐ | Mountains | ☐ | Contract Docs. | ☐ |
| Corridors | ☐ | Desert | ■ | Construction | ☐ |
| Administration | ■ | | | Commissioning | ☐ |
| Toilets | ☐ | | | Operation | ■ |
| Other | ☐ | | | | |

**Recommendation**
Use ceiling fans in classrooms to provide enhanced thermal comfort for occupants through higher air velocity. Use the ceiling fans instead of air conditioners in mild coastal climates. In more extreme climates, use ceiling fans as a supplement to cooling systems.

**Description**
Ceiling fan is a device for creating interior air motion. It is permanent fixture operated by a switch or a pull string. Acceptable comfort levels can be maintained above the customary comfort zone for air speeds exceeding 50 fpm by using a ceiling fan. Generally, for speeds above 30 fpm, most people will perceive a 15 fpm increase in air to be equal to 1°F decrease in temperature (this phenomenon is commonly called 'chill factor'). Outside air can be introduced into a space through openings using a fan when outside air cannot enter the space on its own because it's either too humid or too hot. A fan can also re-circulate air within a space. Fans also cool by increasing evaporation of moisture from the skin (skin moisture vaporizes using body heat to change phase).

In a high ceiling space, ceiling fans can help 'destratify' the warm air layer which collects near the ceiling and distribute it to the lower part of the space for thermal comfort. This can mean that heating thermostats need not be set as high.

The interior air motion cause by ceiling fans varies as a function of fan position, power, blade speed (measured in rpm), blade size, and the number of fans within the space. Moreover, air speeds within a space vary significantly at different distances from the fan.

The normal current draw will range from approximately 15 W at low speed to 115 W at high speed.

**Applicability**
Ceiling fans are appropriate for classrooms and administration areas. They may not be suitable for gyms because of concerns of rapid skin cooling (more skin moisture is secreted during intense physical activities). Nor are they appropriate for toilets as the space may be too small for a ceiling hung fan. Noise produced by ceiling fans may be an issue in auditoriums.

Ceiling fans are suitable for most climates that require cooling. Combined with other passive strategies they may eliminate the need for air conditioning in the north coast region. They are not very useful in humid climates.

Ceiling fans should be considered in the design development stage due to electrical wiring issues, although adding fans to existing spaces is feasible too.

**Applicable Codes**
Electrical codes apply.

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### Integrated Design Implications

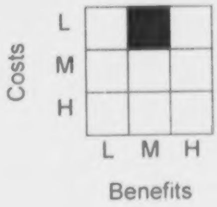
Using ceiling fans does not significantly impact other design decisions.

- A minimum ceiling height of 9' must be provided to accommodate a fan such that its blades are at a distance of 8' from the floor and 1' from the ceiling.
- Ceiling fans should be combined with natural ventilation strategies for best results.

### Costs

Ceiling fans cost between $75 and $200. The typical cost of a professionally installed fan is about $250. Fans with features such as light fixtures, reverse or multiple speed settings, and extended warranties may cost more. Ceiling fans are economical to operate as they consume very little energy.

### Benefits



- Moving air extends the comfort range and allows occupants to feel comfortable at higher temperatures. It also helps occupants feel dry. Wind speed is one of the six factors that affect thermal comfort indices like the PMV (Predicted Mean Vote). Increasing air speeds results in PMVs that fall in the comfort zone (for detailed discussion see the Overview section).
- Temperature settings for mechanical cooling equipment can be higher and an energy savings greater than the energy consumption of the fans can be realized. According to the Texas Energy Extension Service, for a 3 ton cooling system costing $550 per season, raising the thermostat from 75 degrees to 80 degrees can reduce the operating cost by $151. Operating a ceiling fan 10 hours a day or more may cost less than $3 per month. For example, a typical fan operating at high speed uses approximately 100 watts of power. Assuming that the fan is operated 5 hours per day with an energy cost of 8 cents per kWh, the cost of operation will be 4 cents per day. At lower speeds this operating cost will be even less. This low operating cost and the potential reduction in cooling and heating cost make the ceiling fan one of the better energy saving devices on the market. As a rule of thumb- each degree rise in a thermostat setting (beyond 78°F) results in a 3-5% saving on cooling energy. If the ceiling fan is supplementing air conditioning, the thermostat of the AC unit may be raised a full 4°F above the standard 78°F setting while still maintaining comfortable space conditions.
- In the heating season, ceiling fans can help bring the warmer air that stratifies near the ceiling down to where the occupants are located. A low speed that does not create a significant breeze is best for this heating season application. Again, the thermostat set point may be lowered by nearly 2 degrees.

### Design Tools

Use the following charts to size ceiling fans according to largest room dimension and room area:

*Table TC-25— Fan diameter selection based on space dimensions*

| Largest Dimension of Room | Minimum Fan Diameter (in.) |
|---|---|
| 12 ft. or less | 36" |
| 12 - 16 ft. | 48" |
| 16 - 17.5 ft. | 52" |
| 17.5 - 18.5 ft. | 56" |
| 18.5 ft. or more | 2 fans |

*Table TC-26— Fan diameter selection based on space area*

| Room Area (sq. feet) | Minimum Fan Diameter |
|---|---|
| 100 | 36 inches |
| 150 | 42 inches |
| 225 | 48 inches |
| 375 | 52 inches |
| 400+ | 2 fans needed |

*Sources: Consumer Guide to Home Energy Saving (1995) by the American Council for an Energy Efficient Economy.*

## Design Details

- Use ceiling fans in frequently occupied spaces.
- A larger fan provides a greater range of airflow settings and ventilates a larger area at lower velocities, with less noise, and only slightly more power than similar smaller units. Use two 48" fans in classrooms (based on 30'x32' classrooms). These will move air most effectively in a 4'-6' radius and somewhat less effectively at for another 3'-4' radius. At the level of seated occupants this will achieve air speeds ranging from 50-200 fpm. Beyond 30 fpm every additional 15 fpm results in a perceived 1°F drop in temperature. The more blade surface, the more air it will catch.
- Ceiling fans work best when the blades are 7' to 9' above the floor and 10" to 12" below the ceiling. Placing fans so the blades are closer than 8 inches to the ceiling can decrease the efficiency by 40%. Fans also require at least 18" of clearance between the blade tips and walls. Two types of mountings are available for ceiling fans- rod and hugger. In rod fans, the motor housing is suspended from the mounting bracket by a rod. With hugger fans, the motor housing is mounted directly to the ceiling box. Hugger fans are not as efficient as rod fans in the down motion, especially at higher speeds. The blades will starve themselves for air when they are too close to the ceiling.
- Use ceiling fans to supplement air movement in natural ventilation strategies.
- Generally speaking, the larger the blades of the fan, the greater the air movement (also such fans are less noisy). Use larger blade pitches (note that as the pitch or blade surface increases, the motor size must be increased or the rpm of the motor will drop). A good ceiling fan should create enough air movement to make the occupant comfortable at 82°F with 80% relative humidity.
- Select a fan with at least a 2-speed control for better regulation of air movement. Variable speed fans are preferable so that the lowest speed can be used in the heating season to accomplish destratification without causing excessive draft. If using a reversible fan, ensure that the fan has a setting low enough to circulate the air without creating too much of a breeze. These fans are best for rooms that tend to build up heat.
- Fans should be on only when the space is occupied otherwise the movement of the motor in also introducing some heat in the room without any cooling benefits. Remember that ceiling fans cool people, not spaces. Consider using an occupancy sensor

## Operation and Maintenance Issues

- Ceiling fans should be operated only when the rooms are occupied. A motion sensor or a clear policy of operating ceiling fans only when using the room is needed.
- Ensure that all blades are screwed firmly into the blade holder and that all blade holders are tightly secured at the fan. This should be checked from time to time (once a year).
- It's important to periodically clean the fan as the blades tend to accumulate dust on the upper side. An anti-static agent can be used for cleaning but no cleaning agents that can damage the finish should be used. Never saturate a cloth with water to clean your ceiling fan. Water introduces the possibility of electrical shock.
- For a fan to perform efficiently it is very important that the blade be flat throughout. Most manufacturers have programs to investigate keeping warpage to a minimum. "Balanced" blades; that

is, blades that are electronically matched at the factory; are sold as balanced four or five blade set depending on the design of the fan. For this reason, never interchange blades between fans.

### Commissioning

- Use durable fans with longer warranties. Use fans with metal motor housings- these may require annual oiling (while plastic motor housings will not) but may have better warrantees and be worth the added maintenance.

### References / Additional Information

*The Certified Home Ventilating Products Directory*, The Home Ventilating Institute (HVI), 30 West University Dr., Arlington Heights, IL 60004-1893. Tel:(708)394-0150.

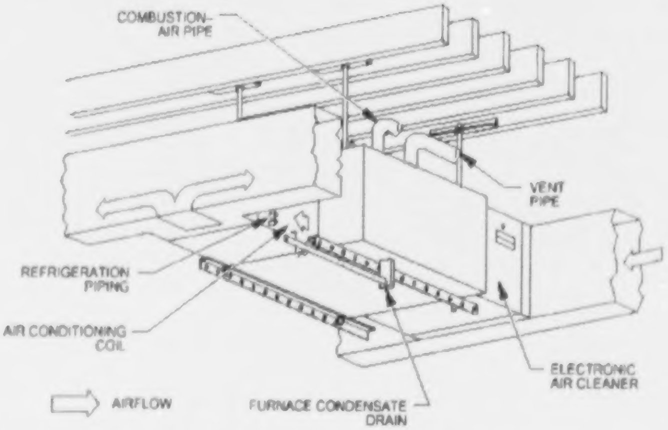
*ASHRAE 62-Ventilation for Acceptable Indoor Air Quality*, ASHRAE, 1791 Tullie Circle NE, Atlanta, GA, 30329-2305. Tel:(404)636-8400; Fax:(404)321-5478.

*Understanding Ventilation: How to Design, Select, and Install Residential Ventilation Systems*, by John Bower, The Healthy House Institute, 430 N. Sewell Rd., Bloomington, IN 47408.

*Oikos/Green Construction Source* (Features REDI 96, an online directory of products, including ventilation fans, devices, and controls.) Iris Communications, P.O. Box 5920, Eugene, OR, 97405-0911, Tel:(541)484-9353, World Wide Web address: http://irisinc.com/oikos

*AIRBASE* (database of over 7,000 abstracts of international papers on infiltration and ventilation), Air Infiltration and Ventilation Centre, Sovereign Court, University of Warwick Science Park, Sir William Lyons Road, Coventry, CV4 7EZ, U.K. Tel:44-203-692050, Fax:44-203-416306.

# Guideline TC4: Gas/Electric Split System



Gas/Electric Split System – Horizontal Installation (source: Carrier)

| Applicable Spaces | | Climates | | When to Consider | |
|---|---|---|---|---|---|
| Classrooms | ■ | South Coast | ■ | Programming | ☐ |
| Library | ☐ | North Coast | ■ | Schematic | ■ |
| Multi-Purpose / Cafeteria | ☐ | Central | ■ | Design Dev | ☐ |
| Gym | ☐ | Mountains | ■ | Contract Docs | ☐ |
| Corridors | ☐ | Desert | ■ | Construction | ☐ |
| Administration | ☐ | | | Commissioning | ☐ |
| Toilets | ☐ | | | Operation | ☐ |
| Other | ☐ | | | | |

## Recommendation

When specifying a gas/electric split system consider an add-on economizer, two-speed blower/furnace/compressor, high efficiency furnace (AFUE 90+) and high efficiency cooling (SEER 14+).

## Description

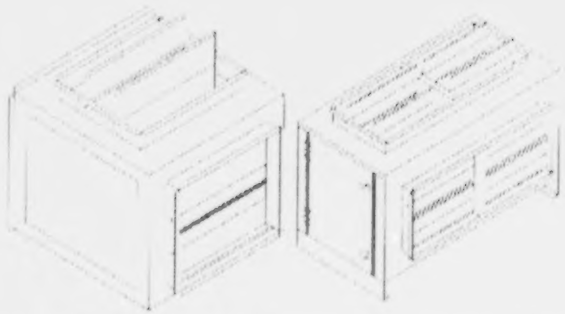
This system is similar to a typical residential heating and cooling system. The components include an indoor fan unit and outdoor compressor and condenser package. The indoor unit usually includes a cooling coil and furnace section, although the furnace can be omitted if the compressor is also used for heating in heat pump mode. The indoor and outdoor sections are connected via refrigerant tubing and control wires.

Supply air from the indoor unit is typically ducted to several supply diffusers in the ceiling. Return air may be ducted or returned directly to the unit through a grill.

While most residential systems recirculate indoor air only, for schools an outside air duct supplies ventilation air that is mixed with return air.

## Variations and Options

An economizer is not standard with split systems but is available as an aftermarket option. The additional equipment includes a mixing box with outdoor and return air dampers and the associated controls. Check with split system manufacturer for control compatibility.



*Mixing Boxes for Economizer Control with Gas/Electric Split System (source: Canfab)*

For climates where cooling is unnecessary, then the system can be used for heating only. Eliminating the cooling coil and outdoor compressor unit reduces the cost significantly. An economizer may be installed to provide free cooling if the space design does not allow for convenient natural ventilation cooling (due to drafts, outdoor noise and dust or similar problems).

Indoor units are available for either horizontal or vertical installation. Horizontal units are typically installed above the ceiling. Vertical units may be installed in a mechanical closet with flow direction either upwards or downwards.

A high efficiency condensing furnace is available as an option for most split systems. Efficiency (AFUE) is 90 to 96 percent, compared to about 80 percent for standard units.

High efficiency cooling is also an option provided by most manufacturers. Systems are available with efficiencies greater than SEER 14, compared to typical units with SEER 10 to 11.

A two-speed blower and variable output furnace is an option that can provide significant fan energy savings and improve comfort through less on/off cycling.

Two speed compressors are available that can be controlled together with a two-speed indoor fan for better comfort and humidity control.

Heat pump heating is an option for locations without convenient natural gas access. In cool climates, a supplementary electric resistance heating element may be necessary, especially to handle relatively high ventilation air requirements for classrooms.

Gas engine driven heat pumps are available. These units use a reciprocating gas engine rather than an electric motor to drive the compressor and provide heating and cooling.

### Advantages

- High heating and cooling efficiencies available (By contrast, efficient heating options are seldom available for packaged rooftop units).
- Two speed fan and compressor options improve partial load efficiency, comfort and humidity control.
- Great number of system capacities are possible with combinations of furnace units, cooling coils and compressors.
- Can add an economizer to take advantage of outdoor air for free cooling (see Guideline TC17: Economizers)
- Outdoor unit is relatively small.
- Possible to keep all ducts within the insulated building shell to minimize impact of duct losses.
- Moderate initial cost.

- Can be installed as a heating-only system at lower cost. A cooling coil and outdoor condensing unit can be added later if desired.

### Disadvantages

- Requires space within the building shell for the indoor unit, either above the ceiling or in a closet.
- Indoor unit may create noise in the space if not carefully designed and installed.
- Requires air ducts, which can be leaky and inefficient if not installed properly.
- High efficiency units have a significant cost premium.
- Limited multi-zone capability.
- Poor dehumidification control (better with two-speed compressor and fan).
- Higher maintenance cost for large facilities compared to central VAV system.

### Applicability

This system type is appropriate for classrooms or other single zone spaces up to about 2,500 $ft^2$.

### Applicable Codes

Minimum cooling efficiency is SEER 10.0 for split systems smaller than 65,000 Btu/h of cooling capacity. Minimum heating efficiency is 78% AFUE for gas furnaces smaller than 225,000 Btu/h. These efficiency requirements are Federal regulations.

Outdoor air ventilation (see this topic in the Overview section.)

Temperature control (see Guideline TC23: Adjustable Thermostats)

### Integrated Design Implications

Location of the indoor and outdoor units needs to be considered early in architectural design to ensure optimal performance. See Design Details below for important considerations. Similarly, location of ducts and supply registers should be considered when making structural and lighting system decisions.

System controls should be specified so they integrate with natural ventilation design. Use automatic interlock controls to shut off then system when windows are opened or allow manual fan shutoff. If the space is designed for good natural ventilation, then an economizer may not be necessary.

Try to place ducts within the conditioned envelope to minimize the impact of leakage and conduction losses (with can be very significant). Insulate under the roof deck rather than on top of a suspended ceiling. If possible, place the indoor unit within the conditioned envelope as well. Ensure, however, that combustion air is properly vented.

### Costs

Overall system cost for a gas/electric split system ranges from $10 to $15 per square foot.

A high efficiency (condensing) furnace adds roughly $700 compared to a standard efficiency unit with base installed cost of about $550. However, the extra cost may also cover multi-speed fan control and variable furnace output in addition to better efficiency.

An efficient three-ton air conditioner with 13 SEER costs roughly $2,500, compared to $1,700 for a SEER 10. The incremental cost is roughly $800.

An outside air economizer adds about $300 to $500.

Considering a 960 $ft^2$ classroom, the incremental cost for combined measures is roughly $2,000, or $2 per square foot of floor area.

## Cost Effectiveness

High efficiency cooling is generally cost effective in warm regions. A high efficiency condensing furnace should be cost effective in cool climates, especially considering construction cost savings due to more flexibility in locating the low-temperature flue vent.

| Costs | L | M | H |
|---|---|---|---|
| L | | | |
| M | | ■ | |
| H | | | |

Benefits

## Design Details

Indoor unit location considerations:

- Noise. Isolate the unit from the occupied space and provide adequately sized ducts and registers to avoid excessive air velocity.
- Make sure that filters and coils are easily accessible for maintenance.
- Provide easy access for the outdoor air inlet, minimizing length of ducts and eliminating turns from ductwork if possible.
- Allow access to outdoors for furnace combustion air and provide a vent for flue gas as recommended by the manufacturer.
- Minimize the number of duct turns necessary to reach supply diffusers and return grilles, and minimize length of ducts (second priority compared to number of turns). At the same time, however, ensure that noise transmission through the ducts is controlled.
- Consider that cooling coil condensate must drain to a proper receptacle and condensate pan overflow should drain to a visible location.
- See also Guideline TC18: Air Distribution for information about choosing locations for supply and return registers to minimize noise and maximize performance.

Outdoor unit location considerations. (Typically the unit is placed on a concrete pad alongside the building. However, rooftop installation is possible as well):

- Noise. Keep away from operable windows and doors.
- Potential for vandalism.
- Access for maintenance.
- Try to choose a shaded location with lowest possible ambient air temperature to improve cooling efficiency. Be especially careful to avoid direct exposure to afternoon sun.
- Provide adequate clearance around the outdoor unit to prevent airflow obstructions.
- If the outdoor unit is mounted on the rooftop, then consider using a reflective white roof membrane to reduce temperature and improve system performance. Standard roofs exceed 150°F on a sunny day, while white roofs can be 50°F cooler.

Match the compressor and indoor fan units for proper performance. See manufacturers' literature for combinations and their efficiency ratings.

Be sure to allow for furnace condensate drainage for high efficiency units, and provide condensate drainage for cooling coils.

Design the air distribution system to minimize pressure drop and set blower fan motor to low or medium speed to reduce fan energy consumption and minimize noise (see Guideline TC18: Air Distribution).

Do not oversize heating and cooling capacities (see the topic Load Calculations in the Overview section).

If choosing a system with multiple speed fan and variable heating and cooling capacity then specify a thermostat with those control capabilities.

### Operation and Maintenance Issues

Maintenance requirements for a gas/electric split system are very similar to other system types. However, all compressor cooling systems require additional maintenance skills and cost more to maintain compared to heating-only systems.

Recommended maintenance tasks include:

- Replace filters regularly.
- Clean coils regularly (indoor and outdoor).
- Check refrigerant charge.
- Clean cooling coil condensate pan and drain.
- Lubricate and adjust fan as recommended by manufacturer.

### Commissioning

Measure total supply air flow with a flow hood or comparable measuring device. Make sure that airflow is within 10 percent of design value. If airflow is low, then check ducts for constrictions and check that filters and coils are free of obstructions. Larger ducts or shorter duct runs may be necessary. Reduce the number of duct turns to a minimum. If airflow is high, then reduce fan speed if possible according to manufacturer's instructions.

If an economizer is installed, then verify it's proper operation (see Guideline TC17: Economizers).

### References / Additional Information

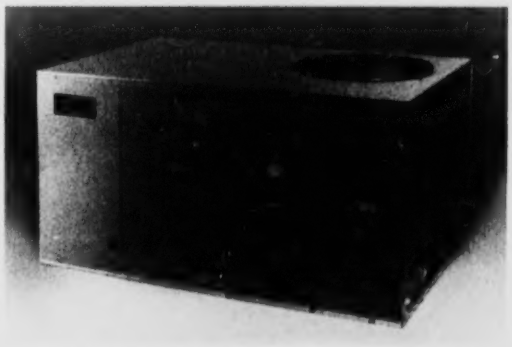
Guideline TC17: Economizers

Guideline TC18: Air Distribution

# Guideline TC5: Packaged Rooftop System

## Recommendation

If choosing a packaged rooftop system, then specify a high efficiency unit, consider specifying an integrated economizer (depends on the space's natural ventilation design), and design the duct system to allow proper airflow at low or medium fan speed.



*Packaged Rooftop System (source: Trane)*

| Applicable Spaces | | Climates | | When to Consider | |
|---|---|---|---|---|---|
| Classrooms | ■ | South Coast | ■ | Programming | ☐ |
| Library | ■ | North Coast | ■ | Schematic | ■ |
| Multi-Purpose / Cafeteria | ■ | Central | ■ | Design Dev | ☐ |
| Gym | ■ | Mountains | ■ | Contract Docs | ☐ |
| Corridors | ■ | Desert | ■ | Construction | ☐ |
| Administration | ■ | | | Commissioning | ☐ |
| Toilets | ■ | | | Operation | ☐ |
| Other | ■ | | | | |

## Description

A packaged rooftop system is fully self contained and consists of a constant volume supply fan, direct expansion cooling coil, heating (when required) with gas furnace, filters, compressors, condenser coils and condenser fans. Units are typically mounted on roof curbs but can be also mounted on structural supports or on grade. Package rooftop single zone units are typically controlled from a single space thermostat with one unit provided for each zone. Supply air and return air ducts connect to the bottom (vertical discharge) or side (horizontal discharge) of the unit.

## Variations and Options

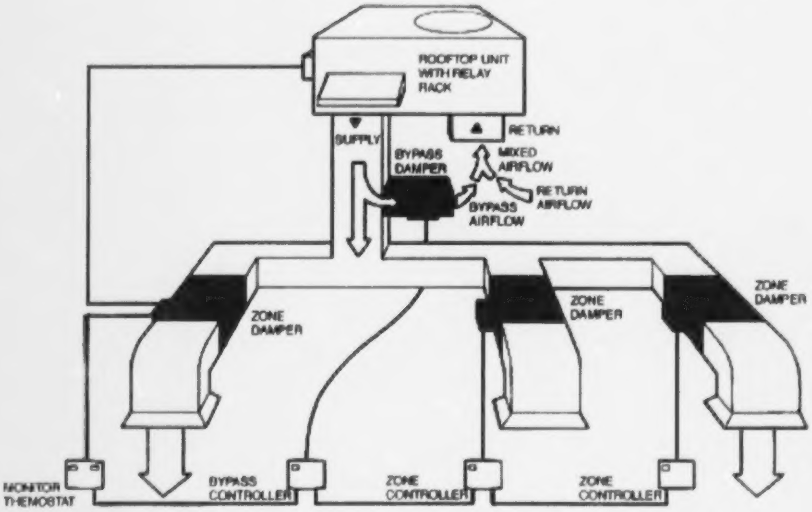
Economizers are a standard option that are often cost effective for rooftop units (see Guideline TC17: Economizers).

High efficiency cooling may be an option but is less commonly available than for gas/electric split systems.

Units can be purchased as heat pumps for use in areas without convenient access to natural gas for heating.

An evaporative precooler can be added to the condenser to increase capacity and efficiency during hot weather (see Guideline TC15: Evaporatively Precooled Condenser).

A "single zone" rooftop unit can condition multiple zones when equipped with special controls and hardware. This type of system includes an automatic damper in the ductwork for each zone, that modulate to control temperature. If some zones require cooling while others need heating, then the controller switches the rooftop unit between both modes and the zone dampers will open or close as appropriate. This system also includes a bypass damper between the supply and return that is opened to maintain constant airflow through the rooftop unit when one or more zone dampers is closed.


ROOFTOP UNIT WITH RELAY RACK
SUPPLY
RETURN
BYPASS DAMPER
MIXED AIRFLOW
RETURN AIRFLOW
BYPASS AIRFLOW
ZONE DAMPER
ZONE DAMPER
ZONE DAMPER
MONITOR THEMOSTAT
BYPASS CONTROLLER
ZONE CONTROLLER
ZONE CONTROLLER

*Variable-Volume and Temperature System (source: Carrier)*

**Advantages**

- Low initial cost
- Uses no inside mechanical equipment space
- Can add an economizer to take advantage of outdoor air for free cooling (see Guideline TC17: Economizers)
- Widely available.

**Disadvantages**

- Fewer efficiency options available compared to gas/electric split systems (e.g. condensing furnace, two-speed fan, high efficiency cooling)
- Relatively large, requires roof space.
- Requires air ducts, which can be leaky and inefficient if not installed properly.
- Limited multi-zone capability
- Poor dehumidification control
- Limited capacity to handle ventilation air
- Higher maintenance cost for large facilities compared to central VAV system.
- Typically shorter lifetime than central VAV system.

**Applicability**

A packaged rooftop unit is applicable for spaces that require heating and cooling. However, due to their relatively low cost, they are sometimes installed where only heating is required.

Due to the constant volume fan, this system is most applicable where loads and ventilation requirements are relatively constant, such as in classrooms and libraries. The system is less applicable for intermittent occupancies such as assembly areas.

Packaged rooftop units are available in capacities from two tons to more than 100 tons and can be used for single zones from 600 $ft^2$ to more than 30,000 $ft^2$.

Multiple zones where the zone loads are not too different can be handled with special controls. There is no theoretical limit to the number of zones and commercially available controllers will serve 32 or more. In practice, these controls should be used for no more than a handful of zones. For larger systems, VAV controls will be more effective and efficient.

### Applicable Codes

See Table 27 for minimum cooling efficiency requirements. For units smaller than 65,000 Btu/h, these efficiency requirements are Federal regulations.

Outdoor air ventilation (see the HVAC Overview section)

Temperature control (see Guideline TC23: Adjustable Thermostats)

Title 24 requires an integrated economizer for systems with cooling capacity greater than 75,000 Btu/h and supply airflow greater than 2,500 cfm (see Guideline TC17: Economizers).

### Integrated Design Implications

Rooftop units can have a significant visual impact. Their location should be considered early in the architectural design process to allow for efficient duct layout. In addition, location of ducts and supply registers should be considered when making lighting system decisions.

System controls should be specified so they integrate with natural ventilation design. Use automatic interlock controls to shut off then system when windows are opened or allow manual fan shutoff. If the space is designed for good natural ventilation, then an economizer may not be necessary.

Try to place ducts within the conditioned envelope as much as possible to minimize the impact of leakage and conduction losses (with can be very significant). Insulate under the roof deck rather than on top of a suspended ceiling.

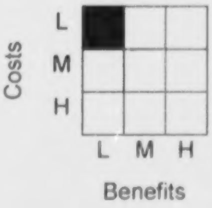
### Costs

The overall cost for a packaged rooftop system can be as low as $10 per square foot (installed cost, including ductwork and controls).

Cost of the unit alone ranges from about $1,500 for a two-ton unit to around $2,000 for a five-ton unit. High efficiency package units (when available) cost about 10% more than standard efficiency models and have paybacks of around 3 to 4 years in warm climates.

### Cost Effectiveness

Packaged rooftop systems are often the lowest cost alternative when both heating and cooling are required. However, they are relatively costly to maintain and energy costs are higher than average.



### Design Details

Most packaged systems have several fan speed options that can be selected in the field when the unit is installed. Careful design of the air distribution system can reduce pressure drop and provide significant savings if the fan is wired for low or medium speed (see Guideline TC18: Air Distribution).

Sizing. The incremental equipment cost for packaged rooftop equipment is not too large to increase size from say, two to four tons. Therefore, the temptation is strong to specify the larger unit for safety's sake. However, there are performance penalties for oversized systems. Bigger is not always better. Do not rely on rules of thumb to select airflow, cooling capacity or heating capacity. See the HVAC Overview section for a discussion of load calculations and the impact of cooling capacity oversizing.

Table 27 lists recommended minimum efficiencies for packaged rooftop equipment.

*Table 27 -- Recommended Minimum Efficiencies for Air-Cooled Packaged Rooftop Equipment*

| Capacity | Title 24 (after 10/29/01) | Recommendation |
|---|---|---|
| < 65,000 Btuh | 10.0 SEER | 12.0 SEER |
| 65,000 – 135,000 Btuh | 10.3 EER | 11.0 EER |
| 135,000 – 240,000 Btuh | 9.7 EER | 10.5 EER |
| > 240,000 Btuh | 9.5 EER | 10.0 EER |

## Operation and Maintenance Issues

Maintenance requirements for a packaged rooftop system are very similar to other system types. However, all compressor cooling systems require additional maintenance skills and cost more to maintain compared to heating-only systems.

Recommended maintenance tasks include:

- Replace filters regularly.
- Clean coils regularly (indoor and outdoor).
- Check refrigerant charge.
- Clean cooling coil condensate pan and drain.
- Lubricate and adjust fan as recommended by manufacturer.

## Commissioning

Measure total supply air flow with a flow hood or comparable measuring device. Make sure that airflow is within 10 percent of design value. If airflow is low, then check ducts for constrictions and check that filters and coils are free of obstructions. Larger ducts or shorter duct runs may be necessary. Reduce the number of duct turns to a minimum. If airflow is high, then reduce fan speed if possible according to manufacturer's instructions.

If an economizer is installed, then verify it's proper operation (see Guideline TC17: Economizers).

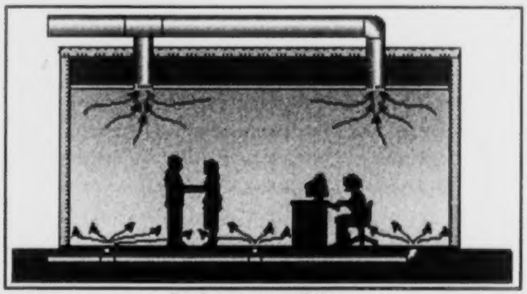
## References / Additional Information

Guideline TC17: Economizers

Guideline TC18: Air Distribution

Guideline TC15: Evaporatively Precooled Condenser

# Guideline TC6: Displacement Ventilation System



**Displacement ventilation.**

*Ventilation System*

*(source: http://www.advancedbuildings.org)*

| Applicable Spaces | | Climates | | When to Consider | |
|---|---|---|---|---|---|
| Classrooms | ■ | South Coast | ☐ | Programming | ■ |
| Library | ■ | North Coast | ☐ | Schematic | ■ |
| Multi-Purpose / Cafeteria | ☐ | Central | ■ | Design Dev | ☐ |
| Gym | ☐ | Mountains | ☐ | Contract Docs | ☐ |
| Corridors | ☐ | Desert | ■ | Construction | ☐ |
| Administration | ■ | | | Commissioning | ☐ |
| Toilets | ☐ | | | Operation | ☐ |
| Other | ☐ | | | | |

## Description

Displacement ventilation systems are different from most other HVAC systems for schools and offer a number of advantages. With displacement systems, air is delivered near the floor, at a low velocity, and at a temperature from 63°F to 65°F (compared to around 55°F for a typical overhead distribution system). The goal of displacement systems is not to cool the space, but to cool the occupants. Cool air flows along the floor until it finds warm bodies. As the air is warmed, it rises around occupants, bathing them in cool fresh air. Air quality improves because contaminants from occupants and other sources tend to rise out of the breathing zone rather than being mixed in the space. Similarly, cooling loads decrease because much of the heat generated by occupants and equipment rises out of the occupied zone and is exhausted from the space.

## Variations and Options

There are several supply air distribution options

- Access floor
- Low wall outlets
- Infloor outlets

The best cooling source for a displacement ventilation system is a chilled water coil. The control valve in a hydronic system allows supply of constant 63°F to 65°F air. A typical DX system is designed to provide colder 50°F to 55°F air while the compressor is running and cycles on and off to meet space loads. This lower temperature and temperature fluctuations would create a comfort problem in displacement ventilation when it comes in contact with occupants. However, larger DX systems with several compressors and temperature reset capabilities can be used as an alternative to a chilled water system. For example, a packaged rooftop VAV system serving 10 or more classrooms should be able to provide the necessary supply air temperature control.

Evaporative cooling is also a potential source because it typically produces higher air temperature than a DX system.

## Advantages

- Lower cooling loads due to thermal stratification.
- May improve air quality compared to systems that mix space air.
- Can provide equal air quality with less outdoor air due to stratification.
- May have lower fan energy with lower static pressure (depends on distribution type and outlet type).
- Ceiling remains clear of supply registers.

### Disadvantages

- Heating performance may be worse than systems providing air at greater velocities. Mixing (i.e. destratification) is desirable for heating.
- Higher first cost.
- Requires some floor area or low wall area for supply air outlets.

### Applicability

Displacement ventilation is most appropriate for spaces with ceiling height of at least 12 feet to permit stratification. It also works best for relatively passive occupants (i.e. not sports facilities).

This system type is most useful in warm climates because the benefits are greatest during the cooling season.

This distribution type is also a great choice where raised access floors are desired for flexibility of power and communication wiring (although access floors are not required for displacement ventilation).

### Applicable Codes

Displacement ventilation systems face the same fan power limits and equipment efficiency requirements as other system types.

### Integrated Design Implications

Supply air outlets must be coordinated with location of furnishings and space usage. The outlets may be integrated with cabinets or seating.

There is an excellent opportunity to integrate electrical and communication wiring with the air distribution either under the floor or along the baseboard.

A displacement system can eliminate the need for a suspended ceiling and allow the ceiling to be clear of supply diffusers.

Displacement ventilation can be integrated into portable classroom design, where space for ducting exists in the crawlspace beneath the floor.

Slab floors may be designed with integral ducts or troughs for air distribution.

Consider use of two-speed or variable-speed heating and cooling sources to minimize the on/off cycling and variations in supply air temperature.

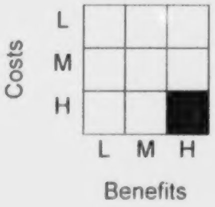
Ceiling fans are not recommended in combination with displacement ventilation because they are designed to mix air in a space and will disrupt the stratification created by the displacement ventilation system.

### Costs

There is not a great deal of experience with displacement ventilation in California classrooms, but it is growing in popularity for new commercial buildings. For the near future, costs are likely to be higher than standard overhead air distribution.

### Cost Effectiveness

A displacement ventilation system will probably not provide a short payback based on energy savings alone. However, the system provides additional comfort and air quality benefits.



### Design Tools

Computational fluid dynamics (CFD) software can help predict airflow patterns within a room and help with the selection and location of supply outlets.

## Design Details

Provide 20 to 30 cfm per occupant (0.6 to 0.9 cfm/ft²) for classrooms depending on cooling loads. At this relatively low airflow rate, 100 percent outside air may be necessary.

Deliver supply air at 63°F to 65°F.

Design for air velocity at supply outlets no greater than 25 to 50 feet per minute. Therefore, displacement ventilation requires significantly larger supply outlets than an overhead distribution system.

Try to place outlets at the corners of the room. Avoid situations where occupants are more than 15 feet from the nearest supply outlet.

Use barometric relief dampers to exhaust the 100% outside air.

Minimum ceiling height is about 12 feet for adequate stratification.

In choosing cooling capacity, consider that loads from lighting and occupants will be reduced compared to a system type that mixes indoor air.

Higher air velocity is desirable in heating mode, so consider a design that reduces supply air outlet area (either manually or automatically) when the system provides heating.

## Operation and Maintenance Issues

Operating and maintenance requirements are similar to other system types.

## Commissioning

Check for proper supply air temperatures. Ensure that air velocity at supply outlets is not too high for comfort. Verify that total airflow meets design requirement.

## Example

Boscawen School, NH,
H. L. Turner Group, Architects

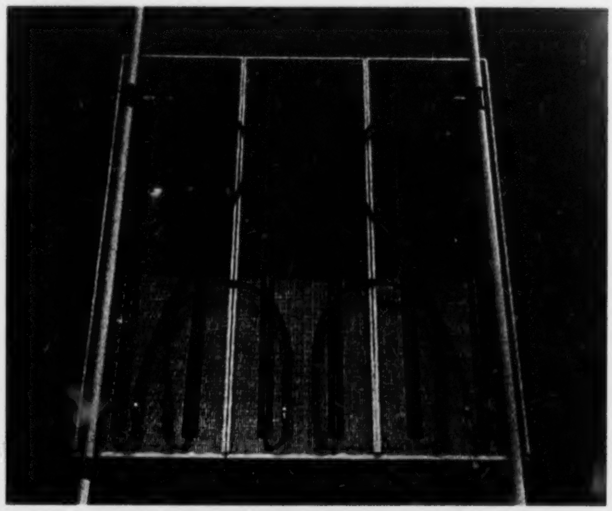
## References / Additional Information

# Guideline TC7: Hydronic Ceiling Panel System

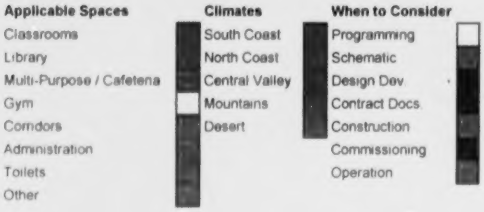
**Recommendation**
Install radiant cooling ceiling panels in arid areas needing significant cooling.

**Description**
A hydronic ceiling panel system provides thermal comfort predominately through radiation heat transfer with objects and occupants. Basic ceiling panel design consists of a metal sheet with copper tubing attached to the upper side and covered with insulation/acoustical inlay material. Applications can take the form of modular panels or wall-to-wall linear design. The system can be suspended, recessed, or placed in a grid configuration. A ceiling panel heating/cooling system involves the following,

- Ceiling panels
- Support system
- Control system
- Hydronic distribution system
- Hot/cold water source



Modular Panel.
Source: Redec - Invensys Building Systems



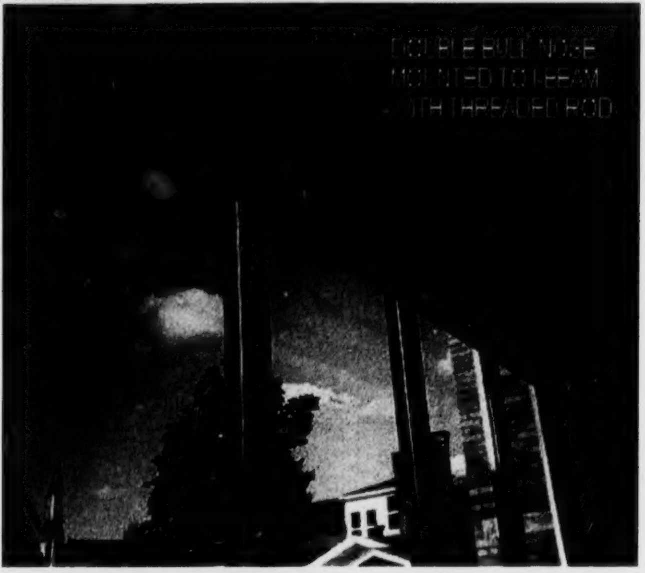
| Applicable Spaces | Climates | When to Consider |
|---|---|---|
| Classrooms | South Coast | Programming |
| Library | North Coast | Schematic |
| Multi-Purpose / Cafeteria | Central Valley | Design Dev. |
| Gym | Mountains | Contract Docs. |
| Corridors | Desert | Construction |
| Administration | | Commissioning |
| Toilets | | Operation |
| Other | | |

**Applicability**
Most applicable in areas with low latent heat load, but can also work in more humid climates with a proper dehumidifying system. Panels can also be used for heating, generally as a substitution for radiators around building perimeter.

## Applicable Codes

There are no requirements specific to hydronic ceiling panels in Title 24. A supplemental ventilation system (mechanical or natural) must be used to meet IAQ standards. Exposed piping must be insulated in accordance with Section 123 of Title 24. If the system is cooling-only the insulation requirement will be minimal. Insulation is not required for water temperatures greater than 60 °F and inlet water temperatures for ceiling panel systems are typically between 58 and 65 °F.

## Integrated Design Implications



*Extruded Aluminum Linear Panel.* *Source: Sun-El Corporation*

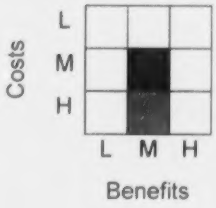
- Hydronic ceiling panel systems provide no outside air ventilation and thus fresh air must be supplied with either operable windows or an air handling system.
- Choosing any hydronic cooling system affects hot and chilled water decisions (solar thermal, chiller, boiler etc.).
- Placement of system components affects requirements of the hydronic distribution system. Try to make these decisions early in order to create a hydronic distribution layout that minimizes piping materials (pipes, bends, etc.) and head loss.
- Depending on regional weather characteristics and required panel water temperature, an air conditioning system may be required to remove excess latent heat load and avoid condensation.
- Can possibly be integrated with building sprinkler systems to lower installation costs. Check with fire marshal to ensure this does not violate fire code regulations.
- Required temperatures can be attained by a heat pump or possibly a cooling tower.
- Acoustic properties of the panels need to be considered.
- If the system is to be used for both heating and cooling a choice between a two-pipe and four-pipe system must be made. This decision will affect the hydronic distribution system.
- Must use heavy duty ceiling grid and provide space in plenum for hangar support.
- Can be integrated into a facility wide hydronic heating and cooling system including baseboards and radiant slabs.

- Effectiveness of panels related to architectural and daylighting decisions regarding ceiling height. Performance of panel system degrades with increasing ceiling height.

## Costs

Price for installed panels is roughly \$18/ft$^2$ of active ceiling area. This does not include costs for control system, hot/cold water supply, or hydronic distribution. Installed cost for modular and linear panels is roughly equal.

## Benefits



- Hydronic systems can decrease or eliminate the need for mechanical air handling systems. This can provide a duct credit under Title 24.
- The water pumping system does not create as much internal heat as air fans do.
- Aluminum panels present possibility of high recycled content material use.
- Added cooling comfort due to lower perceived temperature.
- Low noise. Good for classrooms.
- Energy demand significantly lower than that for air systems due mostly to savings in fluid transport systems.
- Quick response time.

## Cost Effectiveness

- Supplier reports that 10 year savings are substantial
- Operation and maintenance costs are low. Fuel costs are lower due to increased efficiency compared to air handling systems.
- The system is generally most cost effective when part of a facility wide hydronic heating and cooling system.

## Design Tools

- Invensys/REDEC provides an AutoCAD based program for layout design and excel based spreadsheets for sizing calculations.
- RADCOOL is a software program developed by Lawrence Berkeley National Laboratory for modeling buildings with radiant cooling systems.
- EZ-Radiant software from Radiant Tech in New York state covers design for floor, ceiling, and baseboard radiant systems.
- Design and sizing procedure is documented in Chapter 6 of the 2000 ASHRAE Systems and Equipment Handbook.

## Design Details

- If the panels are to be used for heating and cooling a two or four pipe system can be used. A two-pipe system is cheaper and will work for applications with infrequent changeover from one mode of operation to another. If frequent changeovers occur it is best to use a four-pipe system.
- Panel performance is dependent upon room air and panel water temperatures and thermal resistance of panel. Cooling performance for modular panels is generally around 27 BTU/hr-ft$^2$ with an 18°F temperature difference between room air temperature and mean water temperature. Extruded linear panels absorb from 40-50 BTU/hr-ft$^2$ with the same temperature difference. In either case, performance degrades with increasing ceiling height. Heating performance ranges from 40 to 200 BTU/hr-ft$^2$ for mean water temperatures of 120 and 180°F and a 70°F room temperature.

- Cooling water temperatures are generally between 58 and 65°F depending on dewpoint.
- Heating water temperatures are usually between 120 and 180°F.
- Panels located above occupants should not exceed a 95 °F surface temperature for comfort reasons. Higher temperatures may be used for panels that do not extend more than 3 ft into the room. These high temperature panels can be used in lieu of baseboard radiators to heat glass surfaces and exterior walls in order to decrease downdrafts.
- Water temperature should be kept at least one degree higher than the dewpoint temperature at all times.
- Temperature rise for cooling systems should be less that 5 °F and temperature drop for heating systems less than 20 °F.
- Be sure water flow rate is in proper range. Too high can cause noise and too low can result in a significant decrease in heat transfer rate due to laminar flow.
- Panels can be perforated and installed with special inlay material to improve acoustical properties.
- In order to avoid condensation a control system must be used. The system can either use flow control or temperature control. A flow control system uses humidity sensors, temperature sensors, and control valves. It is an on-off system; as soon as the water temperature reaches the dew point temperature the control valve closes. This system is cheap and simple but can make the system useless for extended periods. A temperature control system uses similar sensors and a 2 or 3-way valve to adjust water temperature and avoid condensation. This system is more complex, but it allows for system operation when humid conditions exist.

### Operation and Maintenance Issues

Normal hydronic O&M issues such as checking pumps, valves, pipe leaks, water quality/pipe fouling (important for sustaining maximum heat transfer and minimum pressure drop in open systems). Significant maintenance does not appear to be an issue. Ceiling panel suppliers Redec and Sun-El report repair business is minimal. The ceiling panels have a life expectancy in excess of 30 years.

### Commissioning

Commissioning should be performed throughout planning, design, construction, and operation to ensure proper installation, set-up, and integration with other facility components. The ceiling panel array(s) should be documented with an infrared camera during TAB work to guarantee even cooling and/or heating.

### Examples

Preparation Room in Challenger Learning Center, Phoenix, Arizona. System uses 2x4 ft REDEC CBA-C modular Panels for 15/16" T-Grid with micro perforation and sound absorbing mats.

Several VA Hospitals

San Francisco Pier One Project

Invensys/REDEC call center in Illinois is being built with both a VAV system and a radiant panel system and an extensive array of sensors. Data will be taken using each system separately and the results posted on the web in the near future.

### References / Additional Information

Lawrence Berkeley National Laboratory, Berkeley, California
Operated by the University of California for the U.S. Department of Energy
2000 ASHRAE Systems and Equipment Handbook

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# Guideline TC8: Unit Ventilator System

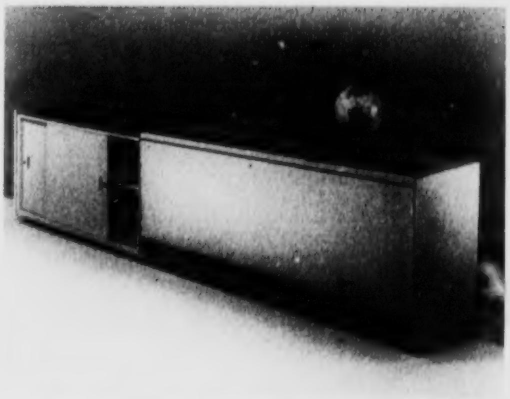
## Recommendation

If choosing a unit ventilator system, specify units with multiple-speed fans, two-way control valves and economizer controls. Also specify variable-flow chilled water and hot water distribution systems.

## Description

Unit ventilators, sometimes called classroom ventilators, provide heating, cooling and ventilation for a single space. The units consist of constant volume fans, chilled water and hot water coils (typical), filters, and outdoor and return air dampers all enclosed in a heavy gage metal housing. Ventilation and/or economizer air is drawn from adjacent openings in the outside wall. Relief is either by gravity or powered exhaust remote from the unit.

A unit ventilator can be mounted in a vertical or horizontal position. A typical installation is a vertical discharge unit on the floor against an exterior wall. However, horizontal discharge units may be suspended from the ceiling or hidden above the ceiling.



*Unit Ventilator, aka Classroom Ventilator*

*(source: Trane)*

| Applicable Spaces | | Climates | | When to Consider | |
|---|---|---|---|---|---|
| Classrooms | ■ | South Coast | ■ | Programming | ☐ |
| Library | ■ | North Coast | ■ | Schematic | ■ |
| Multi-Purpose / Cafeteria | ☐ | Central | ■ | Design Dev | ☐ |
| Gym | ☐ | Mountains | ■ | Contract Docs | ☐ |
| Corridors | ☐ | Desert | ■ | Construction | ☐ |
| Administration | ☐ | | | Commissioning | ☐ |
| Toilets | ☐ | | | Operation | ☐ |
| Other | ☐ | | | | |

## Variations and Options

A unit ventilator may be part of a two-pipe or four-pipe hydronic distribution system.

A two-pipe system (i.e. one supply pipe and one return pipe) is also known as a changeover system if it provides both heating and cooling. The same piping is used for both hot water and chilled water, and the central plant produces either one or the other. During mild weather periods, the system may be required to switch from heating to cooling as the day warms up. Therefore, two-pipe systems must be designed to account for the potential thermal shock to the equipment.

Four-pipe systems can circulate hot water and chilled water throughout the facility simultaneously. The advantage is better zone control because some zones may be heating while others are cooling. The main disadvantage is higher cost.

The control valve within a unit ventilator may be a two-way or three-way valve. In both cases, the valve modulates the flow of water through the coil. The difference is how the valve affects flow in the rest of the distribution system. A three-way valve provides a bypass so total flow through the unit ventilator is constant even though flow through the coil changes. A two-way valve modulates the total flow through the unit ventilator. A distribution system with two-way valves will have variable flow and potentially lower pumping energy consumption, especially if pumps are controlled with variable speed drives.

Economizer controls are an option for some units. A actuator controls the integral outdoor air and return air dampers to take advantage of free cooling when it's available.

Direct expansion cooling may be an option in place of a chilled water cooling coil.

Alternatives to hot water heating include steam coils and heat pumps.

Some unit ventilators offer a heat recovery option that uses exhaust air to either preheat or precool the outdoor ventilation air. Options for this heat recovery function include an air-to-air heat exchanger and a heat pipe.

Some manufacturers offer matched cabinetry to make the unit ventilator look like part of the furnishings.

### Advantages

- Avoids duct losses.
- Cooling can be very efficient if water-cooled chillers and a well designed pumping system are installed.
- Constant, or slowly varying, supply air temperature (through modulation of control valves).
- Multiple speed fans are available in some units.

### Disadvantages

- Poor air distribution, subject to drafts.
- Noise.
- Relatively high first cost.
- Relatively inefficient fans.
- Console units take up floor space within the room.

### Applicability

Classrooms, other spaces with exterior wall access.

Facilities with central chilled water and hot water distribution. Typically large schools that are fairly centralized (to minimize length of chilled water and hot water distribution piping).

Useful where ceiling height is restricted because ducts are unnecessary.

### Applicable Codes

No unit ventilator efficiency requirements for hydronic systems. However, chillers, boilers and piping face requirements (see Guideline TC21: Chilled Water Plants, Guideline TC22: Hot Water Supply, Guideline TC20: Hydronic Distribution).

An economizer is not required for unit ventilators smaller than 2500 cfm, which includes typical classroom units.

### Integrated Design Implications

A unit ventilator requires more coordination with classroom space planning than most other system types. Casework systems are available to integrate the unit with classroom fixtures. An exterior wall with clean outdoor air must be available for unit ventilator installation.

Hydronic distribution frees up space normally reserved for ducts, permitting lower floor to floor heights or enabling higher ceilings and better daylighting performance.

With unit ventilators as well as other hydronic system types, pay attention to site planning and building layout to minimize the length and complexity of piping between the central plant (chiller and/or boiler) and the terminal units.

As with other system types, controls should be designed to allow simple manual or automatic interlock with natural ventilation systems. In addition, economizer controls may be unnecessary if the space is designed to encourage occupants to use operable ventilation openings during mild weather.

## Costs

A system consisting of unit ventilators, a chiller, boiler and two-pipe distribution costs roughly $14 to $16 per square foot of floor area served. Cost for a four-pipe system is $17 to $18 per square foot.

## Cost Effectiveness

A unit ventilator system may be cost effective in specific cases, but in most cases other system types will be either lower cost or higher performance.

| Costs | L | M | H |
|---|---|---|---|
| L | | | |
| M | | ■ | |
| H | | | |

Benefits

## Design Details

Ensure that the outdoor air intake area is free from potential pollution sources. Also make sure that locate the unit to minimize drafts indoors.

Specify the lowest possible noise levels. If possible specify a unit with multiple speed fan control so that normal ventilation occurs at low fan speed.

For chiller, boiler, and hydronic distribution system design details see those individual guidelines. Specify 2-way valves in all unit ventilators and variable-flow chilled water and hot water systems.

Load calculations are important, but oversizing of cooling and heating capacity, as long as it is not excessive, is less of a concern with unit ventilators (and with most other hydronic system terminal units) because control valves can modulate output rate. On/off cycling and partial load efficiency degradation is less of a concern. This is especially true with variable speed fan control. Note, however, that overall facility load calculations are still very important for central plant equipment sizing, where oversizing penalties do occur.

Two-pipe systems should be avoided where heating and cooling may be required on the same day (or even the same week). The switch from heating to cooling wastes energy and can take a long time. In some cases the cooling tower and a heat exchanger are used at switchover to cool the loop. The chillers are engaged once the loop has dropped to a tolerable temperature.

## Operation and Maintenance Issues

Unit ventilator maintenance is fairly simple, although chiller and boiler maintenance requires a relatively high skill level.

Maintenance tasks include:

- Clean cooling coil condensate pans
- Replace filters
- Clean coils
- Lubricate fans if required by manufacturers
- Lubricate and adjust outdoor air and return air dampers.

## Commissioning

Check fan speed setting and airflow.

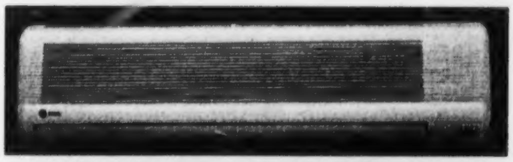
Check control valve operation and thermostat operation. Confirm staging of fan speed if applicable.

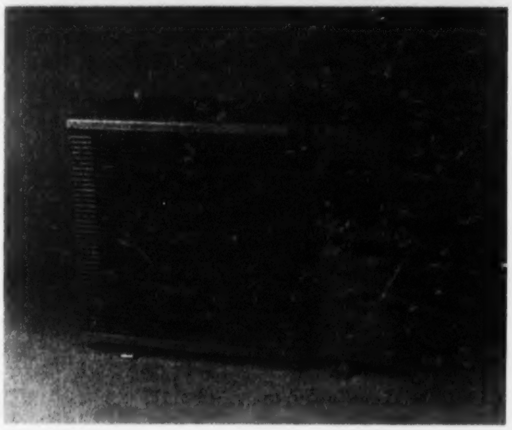
Check coil connections for proper water flow direction.

## References / Additional Information

Guideline TC17: Economizers; Guideline TC20: Hydronic Distribution; Guideline TC21: Chilled Water Plants; and Guideline TC22: Hot Water Supply

# Guideline TC9: Ductless Split System





| Applicable Spaces | | Climates | | When to Consider | |
|---|---|---|---|---|---|
| Classrooms | ■ | South Coast | ■ | Programming | ☐ |
| Library | ☐ | North Coast | ☐ | Schematic | ■ |
| Multi-Purpose / Cafeteria | ☐ | Central | ■ | Design Dev | ☐ |
| Gym | ☐ | Mountains | ☐ | Contract Docs | ☐ |
| Corridors | ☐ | Desert | ■ | Construction | ☐ |
| Administration | ■ | | | Commissioning | ☐ |
| Toilets | ☐ | | | Operation | ☐ |
| Other | ☐ | | | | |

### Recommendation

For ductless split systems specify high efficiency, multiple fan speed and low noise.

### Description

A ductless split system consists of two matched pieces of equipment: an indoor fan coil unit and an outdoor condenser and compressor unit. The two are connected by refrigerant tubing and control wiring that run through the wall or roof. The indoor unit contains a cooling coil, fan, and filter. The outdoor unit includes compressor(s), condenser coil, and condenser fans.

In its simplest form, a ductless split system recycles 100 percent indoor air. However, on many units ventilation air can be supplied with an optional duct attachment that passes through the wall.

### Variations and Options

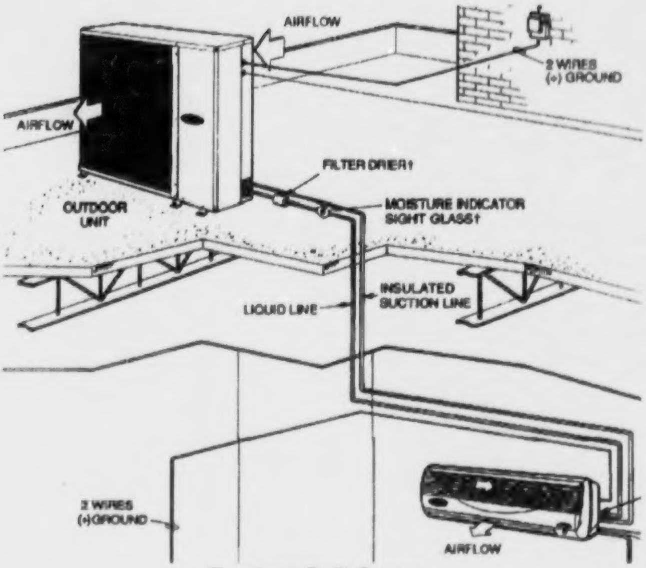
The indoor unit is available in several forms: high wall mount, ceiling mount, and above-ceiling mounting. The high wall mount may be least costly but is usually limited in peak capacity to about two tons. Capacities up to five tons are available with suspended ceiling units. The above-ceiling units typical fit in a 2x2 suspended ceiling system and resemble a typical supply diffuser from below.

Many of these systems can be supplied with a heat pump option to provide heating as well as cooling. Alternatively, heating can be provided through a separate system such as a radiant floor.

Variable speed fans are common and desirable to minimize cycling and reduce noise.

Economizers are available for some, but not all, ductless split systems.

Systems are available that allow two indoor units to be connected to a single outdoor unit.


AIRFLOW
2 WIRES
(+) GROUND
AIRFLOW
FILTER DRIER†
OUTDOOR UNIT
MOISTURE INDICATOR SIGHT GLASS†
INSULATED SUCTION LINE
LIQUID LINE
2 WIRES
(+GROUND
AIRFLOW

Ductless Split System
(source: Carrier)

### Advantages

- Can be utilized where outdoor space is limited
- Compact equipment
- No duct losses
- Simple installation
- Multiple speed fans are commonly available.

### Disadvantages

- Relatively poor indoor air distribution and higher potential for drafts.
- Limited capacity to handle ventilation air.
- Heating option limited to heat pump.
- Less common in North America, where equipment cost is relatively high.

### Applicability

A ductless split system can serve spaces up to about 1,000 $ft^2$, or perhaps 2,000 $ft^2$ if multiple units are installed. They are most useful for buildings with indoor and/or outdoor space constraints, where rooftop space is unavailable or space for ducts is limited.

Ductless split systems are good choices when integrated with natural ventilation that can provide free cooling. For sealed spaces without operable openings, a split system is less desirable because they do not typically have capability to provide 100 percent outdoor air for free cooling.

This system is also applicable for retrofits where ducts do not currently exist.

### Applicable Codes

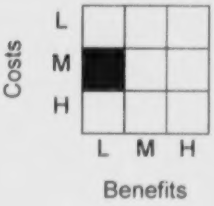
Efficiency, outdoor air and economizer requirements are the same as for gas/electric split systems (see Guideline TC4: Gas/Electric Split System).

### Integrated Design Implications

A ductless split system is a good complement to radiant heating for spaces where cooling is also necessary but infrequent.

### Costs

In North America, ductless split systems are usually more expensive than packaged rooftop systems due to higher equipment cost. The price for a typical 2-ton unit is $4,000 to $5,000.



### Cost Effectiveness

Due to the extra cost, a ductless split system will probably be cost effective only where space constraints prohibit the use of ducted system types.

### Design Details

Place the indoor unit on an external wall for ventilation air access and for minimum distance to the outdoor unit. Follow manufacturers' recommendations for positioning the indoor unit to provide maximum air distribution and to avoid drafts.

Pay attention to security, noise, and ambient temperature when positioning the outdoor unit.

Specify high efficiency units if they are available. Specify low-noise units.

Be very careful not to oversize the unit in order to avoid excessive cycling, which reduces humidity control and irritates occupants. Manufacturers even recommend choosing a system slightly smaller than peak load for these reasons.

Insulate suction and liquid refrigerant lines separately during installation. Otherwise one heats the other causing capacity and efficiency loss.

Water may condense on the indoor cooling coil. Therefore, a condensate pump may be required to remove water from the condensate drain pan to an approved receptacle. Overflow from the drain pan must be routed to a visible location.

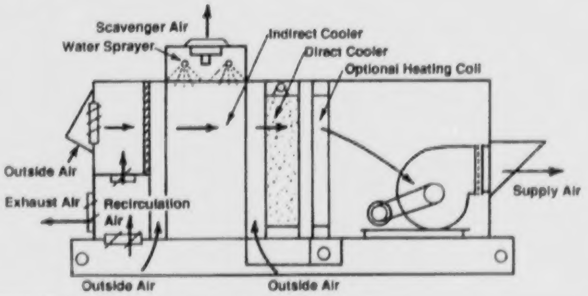
### Operation and Maintenance Issues

Maintenance requirements and operator skills are similar to gas/electric split systems and rooftop packaged systems.

### Commissioning

Verify proper multiple fan speed control operation and thermostat operation.

# Guideline TC10: Evaporative Cooling System



*Evaporative Cooling System*

| Applicable Spaces | | Climates | | When to Consider | |
|---|---|---|---|---|---|
| Classrooms | ■ | South Coast | ■ | Programming | ■ |
| Library | ☐ | North Coast | ☐ | Schematic | ■ |
| Multi-Purpose / Cafeteria | ■ | Central | ■ | Design Dev | ☐ |
| Gym | ■ | Mountains | ■ | Contract Docs | ☐ |
| Corridors | ■ | Desert | ■ | Construction | ☐ |
| Administration | ■ | | | Commissioning | ☐ |
| Toilets | ☐ | | | Operation | ☐ |
| Other | ☐ | | | | |

## Recommendation

Consider evaporative cooling for spaces with high outside air ventilation requirements.

## Description

Evaporative cooling is an alternative way to provide air conditioning. Lower energy costs result because no compressor is needed, only a fan and pump.

Evaporative cooling can be "direct" or "indirect". In a direct evaporative cooling system the water is exposed to the supply air stream. Usually the water flows over an special medium designed to maximize the surface area of water in contact with air, and the air is cooled by the evaporation. The effectiveness can reach 80 to 90 percent, meaning that the drybulb temperature drops by 80 to 90 percent of the difference between the drybulb and wetbulb temperature of the entering air. For example, if entering air temperature is 90°F drybulb and 70°F wetbulb, then the leaving air is cooled to 72°F to 74°F drybulb.

Indirect evaporative cooling is not as effective as direct evaporative cooling but adds no moisture to the supply air. In some systems the air passes through a heat exchanger that is wetted on the outside, where cooling takes place in a secondary air stream. In other systems air passes through a cooling coil supplied with water from a remote cooling tower. Indirect evaporative cooling can be approximately 60 percent effective in reducing the dry bulb temperature of the entering air to its wet bulb temperature. While direct cooling provides 72°F to 74°F air in the example above, indirect cooling could provide 78°F air.

Combining indirect and direct evaporative cooling (as shown in the figure above) further reduces the supply air temperature. When air passes through the indirect cooler first, then drybulb and wetbulb temperature is reduced through sensible cooling. Due to the lower wetbulb temperature, the direct cooler can achieve even cooler temperature for the supply air.

## Variations and Options

Packaged evaporative coolers are available in a wide range of sizes, approximately 3,000 to 20,000 cfm. They are typically roof mounted to supply outside air for the indirect cooling stage.

Packaged air handlers are available that incorporate both indirect and direct evaporative cooling. The evaporative cooling system has an economizer that uses 100 percent outside airflow during cooling mode and minimum outside airflow during heating mode. This allows the use of return air during heating season to keep heating costs equivalent to a standard system. These package units can have hot water coils or duct furnaces installed to provide heating.

If evaporative cooling alone does not satisfy cooling loads, then it can be combined with packaged rooftop cooling by adding direct and/or indirect coolers onto the outside air intake of the packaged unit or it can be integrated directly into the mixed air stream (outside + return) of the packaged unit. Evaporative cooling reduces the load on the DX cooling coil, allowing the compressor size to be reduced, and peak power to be reduced.

Alternatively, a combination of cooling tower and heat exchanger could be used with cooling coils and standard air handlers.

Some indirect evaporative cooling systems are designed to use exhaust air rather than outside air as the secondary air stream, providing heat recovery.

Other systems combine evaporative cooling with a desiccant wheel and/or enthalpy wheel as a method of precooling the outdoor air and increasing cooling capacity.

## Advantages

- Lower electricity consumption and lower peak electric demand.
- Typically use 100% outside air in cooling mode, providing better air quality.
- Smaller electrical supply.

## Disadvantages

- Regular maintenance is more critical than for compressor cooling systems.
- Higher airflow requirements lead to increased fan energy.
- Requires water supply to cooling unit.
- Increased on-site water consumption.
- Does not completely satisfy cooling requirements in some climates.
- Direct evaporative cooling increases space humidity.
- Higher first cost.

## Applicability

Evaporative cooling is most effective in hot, dry climates but it can also be used to completely replace compressor cooling in cold and coastal areas. For areas with higher design wet bulb temperatures, such as Sacramento (100°F/70°F), evaporative cooling can produce most of the space cooling needs. However, if evaporative cooling is used exclusively, space temperatures may rise above 80°F during design conditions.

Evaporative cooling is especially appropriate for spaces with high outside air ventilation requirements such as showers, locker rooms, kitchens or shops. Compressor cooling is often too expensive to operate for these applications.

Combination evaporative and DX cooling only makes economic sense in certain climates and for packaged units over a certain size. Direct and/or indirect evaporative cooling should be considered for packaged units over:

- 20 tons in South Coast (Climate Zones 6 - 10)
- 15 tons in Central Valley (Climate Zones 11-13)
- 10 tons in Desert (Climate Zones 14, 15)

## Applicable Codes

Evaporative cooling systems face no efficiency requirement except for fan system efficiency and heating efficiency.

### Integrated Design Implications

Evaporative cooling is a good match for displacement ventilation systems, which are designed for higher supply air temperature than a typical overhead air distribution system. However, the design will need to accommodate higher airflow that could disrupt stratification. Therefore, careful attention is necessary in locating and sizing supply outlets.

Larger ducts are required compared to a typical compressor cooling system, and duct size may be a consideration in the architectural and structural design.

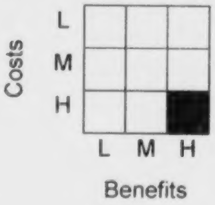
Direct evaporative cooling may not be appropriate for spaces with materials such as wood floors that might be damaged by high humidity.

### Costs

Installed costs are typically greater than for typical packaged air conditioning equipment.

### Cost Effectiveness

Evaporative cooling is usually cost effective in warm and dry climates as long as somewhat higher indoor temperatures are acceptable during hot periods.



### Design Details

An evaporative cooling system requires higher airflow due to higher supply air temperature. Therefore, special attention to duct design and sizing is required to avoid high fan energy costs. The appropriate airflow depends on design conditions for the school's location.

A variable speed or two speed fan is a good idea to allow lower airflow in heating mode.

In warm climates try to use exhaust air as the secondary air stream for indirect evaporative cooling systems.

### Operation and Maintenance Issues

Evaporative coolers demand more maintenance than a typical compressor-based system, so they should be specified only for facilities with qualified maintenance staff or with a qualified outside service company.

To minimize maintenance requirements, specify adequate bleed-off rates to prevent mineral buildup (without causing excessive water consumption). Also specify controls that periodically flush the evaporative medium with water to remove dirt and scale. Finally, specify materials to minimize potential for corrosion.

### Commissioning

Check for correct airflow.

Check for correct water flow rate over the evaporative media.

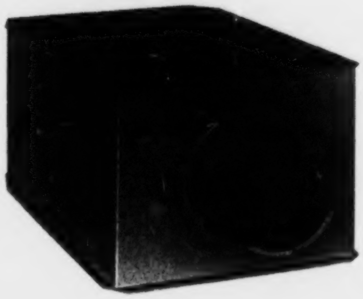
Check the bleed-off rate of water from the evaporative system to ensure that it is adequate to prevent mineral buildup but not too large to cause excessive water consumption.

Verify all modes of operation.

# Guideline TC11: VAV Reheat System

## Recommendation

Choose a VAV reheat system for large administration or classroom facilities, especially multi-story buildings. Specify variable speed fan control, low face velocity cooling coil, bypass damper, supply air temperature reset control and supply duct pressure reset control.



VAV Box

| Applicable Spaces | | Climates | | When to Consider | |
|---|---|---|---|---|---|
| Classrooms | ■ | South Coast | ■ | Programming | ■ |
| Library | ■ | North Coast | ■ | Schematic | ■ |
| Multi-Purpose / Cafeteria | ■ | Central | ■ | Design Dev | ☐ |
| Gym | ☐ | Mountains | ■ | Contract Docs | ☐ |
| Corridors | ☐ | Desert | ■ | Construction | ☐ |
| Administration | ■ | | | Commissioning | ☐ |
| Toilets | ☐ | | | Operation | ☐ |
| Other | ☐ | | | | |

## Description

Variable air volume (VAV) is a general term for a type of HVAC system that supplies only the amount of air needed to satisfy the load requirements of a building zone and can supply different volumes to different zones at the same time. The result is that the total supply of cool air changes over the course of the day, depending on the heat gains in different building areas at different times.

In a VAV system, a central supply fan sends air through medium pressure ductwork to terminal units (VAV boxes) throughout the building. The airflow to each zone—a space or group of similar spaces—is controlled by the VAV box (a "smart damper") which varies the airflow in response to the space temperature. As cooling loads in the zone drop, the damper continues to close until it reaches a minimum position. The minimum position provides the occupants of the zone with adequate ventilation air. Some VAV boxes, especially those in perimeter zones, contain a reheat coil for times when even the minimum airflow is too much cooling. The reheat coil – typically hot water – prevents zones from being overcooled. The reheat coil also provides winter heating, typically during a morning warm-up period prior to occupancy when the outdoor air dampers are closed.

The main system fan is controlled by a duct-mounted pressure sensor which decreases the fan output as the VAV box dampers close.

## Variations and Options

VAV airhandlers may be purchased as factory fabricated units or may be assembled from components in the field (built-up). In either case, cooling can be provided with a chilled water coil or a direct expansion refrigerant coil.

- A common choice for schools is the packaged rooftop variable air volume air conditioning system. The self-contained unit consists of a variable-volume supply fan, direct-expansion cooling coil, heating (when required) with gas furnace, hot water, or steam, filters, compressors, condenser coils and condenser fans.
- Facilities with a central chilled water plant often use factory fabricated air handlers with chilled water coils. In this case, the unit includes a supply fan, cooling coil, filters and perhaps a heating coil.

VAV systems usually include economizer controls.

Several VAV box types are available and some can be combined within the same system.

- Most common for new buildings are pressure-independent boxes with DDC controlled actuators.

- Fan-powered mixing boxes recirculate room or plenum air and are available in two types: series fan or parallel fan. The series fan box requires the fan to operate at all times. The parallel fan box fan activates only when reheat is required.
- Dual-duct VAV boxes contain two dampers controlling a cool duct inlet and warm duct inlet. Typically the warm duct damper is closed during cooling periods. When cooling load drops and the cool duct damper reaches its minimum position, then the warm duct damper begins to open to prevent overcooling in the space.

A dual-fan, dual-duct VAV system is an alternative to VAV reheat and requires less reheat energy. The warm duct recirculates indoor air and adds heat if necessary. The cool duct provides ventilation air and cooling. Rather than using a reheat coil to avoid overcooling at minimum ventilation position, the dual duct system mixes warm return air to offset cooling.

### Advantages

- Better comfort control due to steady supply air temperature (vs. single zone systems that are constant volume and variable temperature).
- Moderate initial cost for buildings that require multiple zones.
- Better dehumidification control than packaged single zones.
- Energy efficiency of variable air volume.
- Larger and more efficient fans than single zone systems.
- Centralized maintenance for coil cleaning and filter replacement.
- Relatively simple to add or rearrange zones.

### Disadvantages

- Higher fan pressure than single zone systems (leads to higher energy consumption).
- Requires more sophisticated controls than single zone systems.

### Applicability

VAV systems are appropriate for administration buildings or large classroom buildings with peak cooling load greater than about 20 tons. The minimum size for a packaged VAV system is about 20 tons.

The overall efficiency of VAV systems depends on the diversity of zone heating and cooling loads. If a particular building has very similar zones and constant loads (such as classrooms with identical occupancy schedules in an extremely well-insulated building), the potential for savings from a VAV system are reduced.

### Applicable Codes

Title 24 restricts simultaneous heating and cooling (e.g. reheat) unless certain conditions are met. Either the system must be capable of reducing airflow to 30 percent before reheating, or reducing to 0.4 cfm per square foot or to 300 cfm, whichever is larger.

Supply air temperature reset controls are required.

### Integrated Design Implications

VAV systems require space for ductwork and should be considered early in the design process.

Requirements for fire separations can affect duct layout and architectural design.

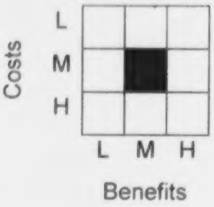
Shaft space may be required in multi-story buildings to deliver air to the lower floors.

## Costs

A typical VAV reheat system costs $16 to $18 per square foot of floor area. This cost is greater than packaged single zone systems and roughly equal to a unit ventilator system.

## Cost Effectiveness

A VAV system is usually cost effective for larger buildings. It is the most common system type for new multi-story commercial facilities.



## Design Details

A variable speed fan is the recommended approach to control duct air pressure in a VAV system although several methods are possible. Variable speed drives are the most efficient and have the added advantage of limiting current inrush for startup of large motors ("soft-start" feature). Other less effective duct pressure control devices are variable inlet vanes, inlet cones, sliding covers, and discharge air dampers.

For direct-expansion (DX) VAV systems, multiple-step unloading or variable speed compressors should be specified. This prevents frosting of the evaporator coil at low cooling loads (this is particularly important for units equipped with economizers). Greater numbers of unloading steps also improves supply air temperature control by allowing a smaller throttling range.

Supply air temperature reset. Specify controls that will adjust the supply air temperature according to demand for cooling. As cooling demand drops, supply air temperature may be increased so that compressors operate more efficiently, and outside air can provide a larger fraction of cooling. However, more airflow is required with higher supply air temperature and at some point the extra fan energy exceeds the cooling energy savings. Carefully consider the characteristics of a specific building when choosing a supply air reset schedule. Computer simulations can help to determine optimal settings.

Supply air pressure reset. Consider controls that will also minimize the supply air pressure required to meet all zone loads. Typically the supply fan is controlled to maintain a constant static pressure of around 1.5 inches w.c. in the duct upstream of the VAV boxes. However, lower pressure may satisfy airflow demands at many times of the year and can save fan energy. Automatic reset controls can monitor damper position in all VAV boxes and lower the supply duct pressure when all dampers are partially closed.

Ventilation air control can be tricky in a VAV system due to varying supply airflow. One option is to modulate the outdoor air damper based on measurement of outdoor airflow. This modulating damper method can also allow demand ventilation control to reduce airflow when spaces have low occupancy (see Guideline TC25: Demand Controlled Ventilation). Another option is a separate outdoor air fan that injects a constant volume of ventilation air into the supply air stream when the system is not in economizer mode.

To minimize reheat energy consumption, set the minimum flow on each VAV box as low as possible. In many cases, reheat would be unnecessary if the minimum flow were zero. However, the need for ventilation air usually requires some minimum damper position. In some systems, heating occurs at minimum airflow. Therefore, heating load can also be a constraint on the minimum flow. In these situations, reverse acting damper control is recommended. As heating load increases, then the damper reopens. Title 24 requires that the minimum zone airflow be not greater than 30 percent peak flow.

The zone thermostats should have separate setpoints for heating and cooling with a deadband in between (as required by Title 24). This control also helps to minimize reheat energy.

Zone controls should also be tied to a central energy management and control system (EMCS). An EMCS reduces operation and maintenance cost by allowing remote monitoring and control.

To minimize air pressure drop across the cooling coils, limit the face velocity to 300 fpm. This requires a larger coil. Also consider specifying a bypass damper that opens when the cooling coil is not needed, such as in economizer mode. Both these measures help reduce fan energy consumption.

Rather than installing a return air fan, consider using a relief fan or barometric relief dampers to minimize fan energy.

Design duct systems to minimize pressure drop and leakage. For recommendations on duct design, see Guideline TC18: Air Distribution.

### Operation and Maintenance Issues

VAV system operation requires a skilled commissioning staff to ensure that controls operate efficiently. However, maintenance is relatively simple once the system is operating. Many tasks are centralized and take less time than for a system with single zone units.

VAV boxes typically have DDC interfaces allowing space conditions to be monitored from a central building management system. The information and remote control capability helps reduce maintenance costs.

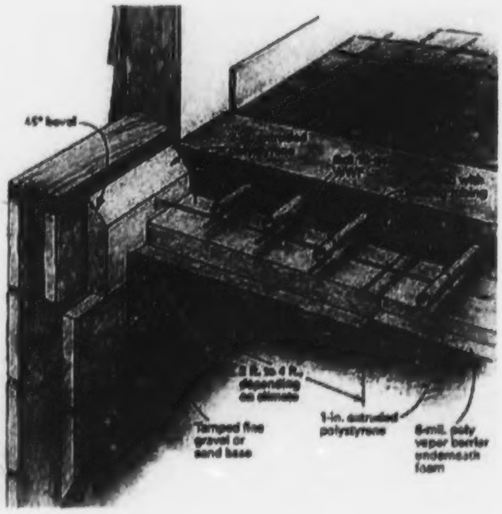
### Commissioning

Calibrate zone airflow sensors, and confirm minimum and maximum flow for each VAV box.

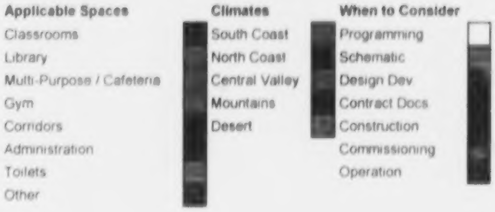
Calibrate all system temperature and pressure sensors. Confirm supply air temperature reset supply pressure reset control operation.

Calibrate outside air flow measurement (if one is installed) and ensure that minimum ventilation airflow is provided under varying conditions.

# Guideline TC12: Radiant Slab System


45° bevel
2 ft. to 4 ft. depending on climate
Tamped fine gravel or sand base
1-in. extruded polystyrene
6-mil. poly vapor barrier underneath foam

Radiant slab



| Applicable Spaces | Climates | When to Consider |
|---|---|---|
| Classrooms | South Coast | Programming |
| Library | North Coast | Schematic |
| Multi-Purpose / Cafeteria | Central Valley | Design Dev |
| Gym | Mountains | Contract Docs |
| Corridors | Desert | Construction |
| Administration | | Commissioning |
| Toilets | | Operation |
| Other | | |

## Recommendation

Install radiant slab-on-grade systems in rooms with heating demand. When conditions permit, use a solar thermal, geothermal system, and/or recovered thermal energy for the hot water supply.

## Description.

A radiant slab heating system consists of the following:

- Hydronic distribution
- Hot water source (boiler, solar, geothermal heat pump, etc.)
- Control System

Like all radiant heating systems, radiant slab systems provide thermal comfort to building occupants predominantly through radiation heat transfer. In other words the system heats or cools room objects and occupants rather than the surrounding air. There are two basic configurations for hydronic radiant slab heating and/or cooling. The first involves the placement of pipes in the foundation slab itself, referred to as slab-on-grade. The second, called thin-slab, consists of piping placed in a thinner slab layer that is situated on top of the foundation slab or on suspended floors. Each consists of a loop of tubing (normally cross-linking polyethylene, PEX) that is imbedded in concrete or a similar material such as gyp-crete. Hot water is passed through the tubing, which heats the slab, and in turn the room.

## Applicability

The use of radiant slabs for heating is applicable in all regions with a heating demand. However, due to condensation concerns, the use of radiant slabs for cooling should be limited to areas with a low latent cooling load.

## Applicable Codes

- There are no requirements specific to radiant slab systems in nonresidential sections of Title 24. (Residential code requires R-10 edge insulation.)
- A supplemental ventilation system (mechanical or natural) must be used to meet IAQ standards.
- Title 24 Section 123 details pipe insulation requirements.

## Integrated Design Implications

- Choosing any hydronic heating system affects boiler decisions (heat pump, solar, etc.).

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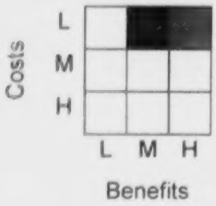
- All radiant hydronic systems provide an alternative to large-scale air handling systems. This impacts many aspects of the building design including the required plenum sizing, boiler/chiller sizing, ducting, etc.
- The slab system is a low temperature application and is complemented well by alternative water heating methods including geothermal heat pumps and solar thermal systems. Typical hydronic heating systems such as baseboard radiators use water temperatures of 140 to 200°F, whereas radiant floor heating uses temperatures between 90 and 120°F.
- Must consider framing strength when installing suspended floor thin slab systems. It is much more cost effective to consider this during design rather than reinforcing the framing during construction.
- Can be integrated into a facility wide hydronic heating and cooling system including baseboards and ceiling panels.
- Placement of system components affects requirements of the hydronic distribution system. Try to make these decisions early in order to create a hydronic distribution layout that minimizes piping materials (pipes, bends, etc.) and head loss.
- Costs. The installed cost of the slab only ranges from $2 to $20 per square foot depending upon application. PEX tubing costs around $0.65 per linear foot retail.



### Benefits

- Hydronic systems can decrease or eliminate the need for mechanical air handling systems. This can provide a duct credit under Title 24.
- Quiet operation.
- Better perceived comfort. Radiant slabs heat occupants from the bottom up and are purported to increase comfort. Allows for lower thermostat settings.
- Lower boiler temperatures of 90 to 120 °F compared to 140 to 200 °F for other heating systems. These temperatures can be accomplished by a geothermal heat pump or solar thermal system.
- Can provide fuel savings when compared to forced air systems.
- Aesthetically pleasing; no heat registers or visible radiators.

### Cost Effectiveness

- Operation and maintenance costs are low. Fuel costs are lower due to increased efficiency compared to air handling systems.
- The system is generally most cost effective when part of a facility wide hydronic heating and cooling system.

### Design Tools

- Use of a CAD based program to design the layout of the tubing is key. This can save time, materials, and money.
- EZ-Radiant software from Radiant Tech in New York state covers design for floor, ceiling, and baseboard radiant systems.

### Design Details

- Install edge insulation around radiant slab.
- Older installations used copper or other metal tubing, but these materials can react with the concrete and corrode if not properly treated. Copper has excellent heat transfer characteristics, but its short coil length and incomplete compatibility with concrete has caused a switch to polymer or synthetic rubber tubing. Most modern installations use cross-linked polyethylene (PEX) tubing. PEX tubing is usually layered with an oxygen diffusion barrier to extend the life of system components. Some

installers use stainless steel components in lieu of the diffusion barrier. Another option is a PEX-aluminum (PEX-Al-PEX) composite tubing where the aluminum acts as a nearly perfect diffusion barrier. PEX-Al-PEX is also easier to bend than standard PEX.

- Any PEX tubing outside of the slab should be protected from sunlight to prevent corrosion.
- Tubing must be routed through the sub soil or in a protective sleeve (PVC) when passing through expansion joints.
- Before pouring the concrete, tubing should be laid out and pressurized to 100 psi for 24 hours to ensure no leakage. The tubing should remain pressurized throughout the pouring and curing process.
- Water should be delivered to the slab at a temperature that can maintain surface temperatures between 80 and 85°F. The required inlet water temperature is dependent upon the thermal resistance of the slab and any floor finishing material.
- Tubes should be spaced between 6 and 15 inches apart depending on application.
- Use tighter spacing for slabs with wood floor finishing. Even temperatures are critical in order to avoiding varying levels of expansion and contraction in wood floors.
- Early planning is key for these systems. This should include an accurate estimate of the load requirements in the rooms to be heated and cooled. Due to the nature of the system (in the foundation slab) the earlier the decision is made the better.
- High quality control systems should be used that monitor both indoor and outdoor temperatures. The slab is a large thermal mass and care must be taken to avoid under or over shooting the prescribed temperature.

### Operation and Maintenance Issues

- The slab system consists of a large thermal mass and thus takes a significant amount of time to respond to changes in control settings. The response time of the system can be through proper operation and maintenance practices that serve to avoid severely over and/or under shooting the desired temperature.
- Modern radiant slab systems require little maintenance and do not have the leakage concerns of earlier systems.

### Commissioning

Commissioning should be performed throughout planning, design, construction, and operation to ensure proper installation, set-up, and integration with other facility components. Proper installation and management of the control system for a radiant slab are of particular importance. Be sure indoor and outdoor sensors are sited correctly and functioning properly.

### Example(s)

Radiant Slab installations by Warm Floors of Napa, California:

- Rudolf Steiner Institute in Sacramento
- Montessori School in Sebastopol
- San Francisco Pier 1 Project
- San Francisco Zoo elephant hold

### References / Additional Information

Warm floors
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1051 Folger Street, Berkeley, CA 94710
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# Guideline TC13: Baseboard Heating System

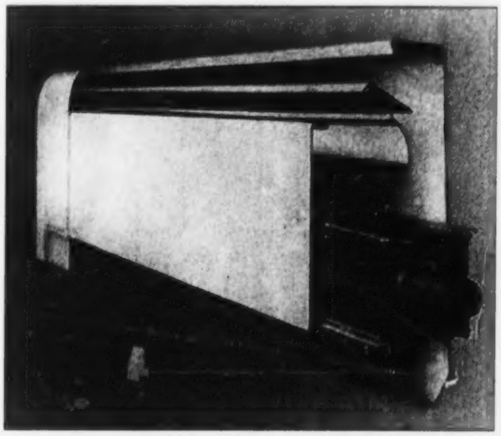
## Recommendation

Use baseboard heating in areas experiencing periods of near-freezing temperatures.

## Description

Hydronic radiant baseboard heating is a common application that has been used for over 50 years in the Unites States. The most common types are the finned-tube convector and radiant convector both of which heat cold air at the floor of the room and induce an upward convective current. This is extremely effective in reducing downdrafts at cold facades and under windows. These models provide heat through a combination of convection and radiation. Another model is the panel, or flat pipe, radiator. Panel radiators are common in Europe and provide thermal comfort predominately through radiation heat transfer. A baseboard heating system requires the following,

- Baseboard heaters (convector or panel)
- Hydronic distribution system (piping, pumps, valves, etc.)
- Control system (sensors, thermostats, etc.)
- Hot water source (boiler, solar thermal, recovered thermal energy, etc.)



*Finned-tube Convector. Source: Embassy Industries Incorporated*

| Applicable Spaces | | Climates | | When to Consider | |
|---|---|---|---|---|---|
| Classrooms | ▨ | South Coast | ☐ | Programming | ☐ |
| Library | ▨ | North Coast | ▨ | Schematic | ▨ |
| Multi-Purpose / Cafeteria | ▨ | Central Valley | ☐ | Design Dev | ■ |
| Gym | ☐ | Mountains | ■ | Contract Docs | ■ |
| Corridors | ▨ | Desert | ☐ | Construction | ▨ |
| Administration | ▨ | | | Commissioning | ■ |
| Toilets | ▨ | | | Operation | ▨ |
| Other | ▨ | | | | |

## Applicability

Applicable in all areas experiencing extreme cold. Especially effective in areas of significant heat loss such as entryways.

## Applicable Codes

- There are no requirements specific to baseboard heaters in Title 24. A supplemental ventilation system (mechanical or natural) must be used to meet IAQ standards.
- Title 24 Section 123 details pipe insulation requirements.

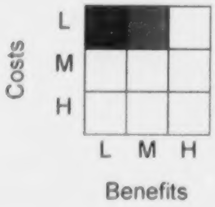
## Integrated Design Implications

- Choosing any hydronic heating system affects boiler decisions (heat pump, solar, etc.).
- All radiant hydronic systems provide an alternative to large-scale air handling systems. This impacts many aspects of the building design including the required plenum sizing, boiler/chiller sizing, ducting, etc.
- Can be integrated into a facility wide hydronic heating and cooling system including radiant slabs and ceiling panels.
- Can be main heat source or integrated with another system and used primarily to reduce downdrafts.

- Placement of system components affects requirements of the hydronic distribution system. Try to make these decisions early in order to create a hydronic distribution layout that minimizes piping materials (pipes, bends, etc.) and head loss.

### Costs

Baseboard heaters cost $10 to $25 per linear foot.



### Benefits

- Hydronic systems can decrease or eliminate the need for mechanical air handling systems. This can provide a duct credit under Title 24.
- Well understood system. Has been used for over 50 years.
- Low maintenance.
- Can be more fuel efficient than air systems.
- Quiet. Good for classrooms.
- Stops cold downdrafts at outside walls and windows.
- System can be configured to allow for individual room control.

### Cost Effectiveness

- Operation and maintenance costs are low. Fuel costs are lower due to increased efficiency compared to air handling systems.
- The system is generally most cost effective when part of a facility wide hydronic heating and cooling system.

### Design Tools

- Advanced Installation Guide for Hydronic Heating Systems available from the Hydronics Institute includes a design and sizing procedure for baseboard heating.
- *Hydronics Design Toolkit* software available from the Radiant Panel Association.
- EZ-Radiant software from Radiant Tech in New York state covers design for floor, ceiling, and baseboard radiant systems.

### Design Details

- Baseboard systems can use zone control or individual room control. Zone control uses one thermostat to regulate several spaces in a single hydronic loop. This system is simple and cheap, but often involves large temperature drops and can be difficult to balance. Individual room control uses thermostatic radiator valves (TRV) to independently control baseboard elements in each space. The TRV allows educators to control the thermal environment of their own classroom.
- Flow rate must be controlled to ensure turbulent flow. If the flow rate is in the laminar regime the heat transfer rate will be dramatically lower and more sensitive to flow rate changes causing difficulties in maintaining intended thermal conditions. Too high a flow rate can cause pipe noise.
- Increases in altitude can decrease the performance of finned-tube and radiant convectors.
- Painting panel radiators can affect performance. Aluminum and bronze paint can reduce total heat output by up to 10%.
- Make allowances for pipe expansion during installation order to decrease audible disturbances.
- Water should be delivered to baseboard radiators between 140 and 200 °F.

- Care should be taken to ensure baseboard surface temperatures do not reach levels dangerous to young children.
- Output ranges from 300 to 800 Btu/hr/ft depending on inlet/outlet temp and flow rate.
- Temperature drop across heater should not exceed 20°F to insure uniform heating.
- Be sure not to inhibit convective flow patterns when arranging furniture near baseboard heating elements.

### Operation and Maintenance Issues

- Operation and maintenance issues for baseboard heating systems are minimal. Heat transfer surfaces should be kept clean and free of dust. If the system is open to the potable water supply some internal cleaning may be necessary to avoid fouling. Pipe fouling can lower efficiency by decreasing the heat transfer rate and increasing the pressure drop.

### Commissioning

Commissioning should be performed throughout planning, design, construction, and operation to ensure proper installation, set-up, and integration with other facility components.

### References / Additional Information

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# Guideline TC14: Gas-Fired Radiant Heating System

Radiant Heaters

| Applicable Spaces | |
|---|---|
| Classrooms | ☐ |
| Library | ☐ |
| Multi-Purpose / Cafeteria | ■ |
| Gym | ■ |
| Corridors | ☐ |
| Administration | ☐ |
| Toilets | ☐ |
| Other | ■ |

| Climates | |
|---|---|
| South Coast | ■ |
| North Coast | ■ |
| Central | ■ |
| Mountains | ■ |
| Desert | ■ |

| When to Consider | |
|---|---|
| Programming | ☐ |
| Schematic | ■ |
| Design Dev | ☐ |
| Contract Docs | ☐ |
| Construction | ☐ |
| Commissioning | ☐ |
| Operation | ☐ |

## Recommendation

Consider gas-fired radiant heating for spaces with high ceilings and potentially high infiltration or in large spaces with spot heating needs.

## Description

This class of radiant heaters burns gas to heat a steel tube or a ceramic surface. The heated surface emits infra-red radiation that is absorbed by occupants, furniture, floor and elements of the building in view of the heating element. Those objects then heat the air in the space through convection. An advantage to this type of radiant heating in high traffic areas is that the objects in the space remain warm even if cool air is introduced.

## Advantages

- Equal comfort with lower indoor air temperatures, resulting in lower heating energy consumption.
- Eliminates fan energy and or pumping energy required for heating distribution.

## Disadvantages

- Occupants may experience some discomfort due to warm heads and cool feet.

## Variations and Options

- Several configurations of gas-fired radiant heaters are available.
- Some are linear units consisting of a long steel pipe with a reflector above.
- Another option is a smaller unit with heated ceramic surface design to cover a rectangular area of floor.

## Applicability

Radiant heating is appropriate in spaces with high ceilings because it helps to overcome thermal stratification. Much of the heat is delivered directly to objects and occupants at floor level.

As mentioned earlier, radiant heating is also useful in areas with high traffic where infiltration can be a problem.

Appropriate spaces include gyms, shops, and high traffic entrances or lobbies.

Radiant heaters can provide spot heating in large open spaces such as workshops or warehouses.

## Applicable Codes

Codes may require an outdoor source for combustion air and/or venting for the products of combustion.

### Integrated Design Implications

Consider the need for combustion air and flue gas venting when choosing the location for a gas-fired radiant heater. Also allow for adequate clearance around the unit, as recommended by the manufacturer.

### Cost Effectiveness

Gas-fired radiant heaters are usually a cost effective choice for spot heating in large open spaces. They may also be cost effective for general heating in spaces like gymnasiums when energy savings are considered.

| Costs | L | M | H |
|---|---|---|---|
| L | | | |
| M | | ■ | |
| H | | | |

Benefits

### Design Details

Provide protection for units installed in gymnasiums to prevent contact with sports equipment.

Follow the manufacturers guidelines for clearance above and to sides.

Provide and outdoor combustion air source and venting of flue gas to outdoors.

### Operation and Maintenance Issues

Gas-fired radiant heaters are relatively low maintenance systems.

# Guideline TC15: Evaporatively Precooled Condenser

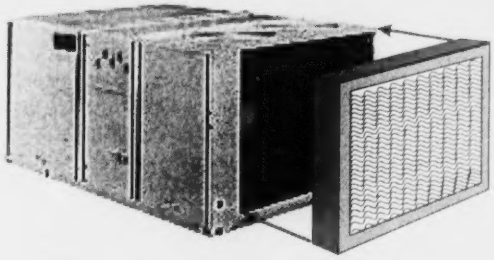
## Recommendation

Specify an evaporatively precooled condenser for larger packaged units (10 tons or greater) in warm climates.

## Description

An evaporative precooler is an option available for some packaged air conditioners that cools the air entering the unit's condenser coils. The precooler reduces the temperature at which the condenser operates and increases the efficiency and capacity of the packaged unit.

The evaporative precooler consists of an evaporative medium several inches thick that replaces the inlet grill that typically protects the condenser coils. The medium is wetted using a recirculating system or a "once-through" system. Air drawn over the medium by the condenser fan is evaporatively cooled to a point close to the wetbulb temperature of outside air.



*Evaporatively Precooled Condenser*

| Applicable Spaces | | Climates | | When to Consider | |
|---|---|---|---|---|---|
| Classrooms | ■ | South Coast | ■ | Programming | ☐ |
| Library | ■ | North Coast | ☐ | Schematic | ■ |
| Multi-Purpose / Cafeteria | ■ | Central | ■ | Design Dev | ■ |
| Gym | ■ | Mountains | ■ | Contract Docs | ☐ |
| Corridors | ■ | Desert | ■ | Construction | ☐ |
| Administration | ■ | | | Commissioning | ☐ |
| Toilets | ☐ | | | Operation | ☐ |
| Other | ☐ | | | | |

Precoolers are also available for outdoor units of some split systems.

## Applicability

For facilities with skilled maintenance staff.

For larger units, especially those serving spaces used in summer.

## Applicable Codes

An evaporative precooler adds no code requirements compared to a standard packaged rooftop system.

## Integrated Design Implications

An evaporative precooler increases the capacity of air conditioners under hot conditions. Therefore, a smaller unit can be installed that will run more efficiently under normal partial load conditions.

Water supply piping is required.

## Costs

Evaporative pre-cooled condensers add about 10% to the cost of the equipment and can pay for themselves in 2 to 3 years.

## Benefits

Increases capacity and efficiency of packaged DX air conditioners.

## Cost Effectiveness

An evaporatively pre-cooled condenser is generally cost-effective for units over about 10 tons in Valley and Desert climates (Zones 11-15).

| Costs \ Benefits | L | M | H |
|---|---|---|---|
| L | | ■ | |
| M | | | |
| H | | | |

## Design Details

Evaporative precoolers are typically controlled to operate only at higher outdoor air temperatures, approximately 80°F and above. At lower temperatures, less benefit is available.

When sizing the packaged rooftop system, reduce the design outdoor drybulb temperature assuming that the evaporative precooler is about 50% effective. For example, in a climate with summer design conditions of 100F drybulb and 70F wetbulb, use an outdoor drybulb of 85F for selecting the system capacity. This smaller system will run more efficiently at part load and have a smaller peak electric demand.

The addition of the evaporative precooler will reduce condenser airflow due to extra pressure drop. Check with the unit's manufacturer to make sure that airflow will be adequate.

Ensure that the precooler medium is properly designed and sized to prevent carry-over of water onto the condenser coils.

## Operation and Maintenance Issues

To minimize maintenance requirements, specify adequate bleed-off rates to prevent mineral buildup (without causing excessive water consumption). Also specify controls that periodically flush the evaporative medium with water to remove dirt and scale. Finally, specify materials to minimize potential for corrosion.

Periodic cleaning of evaporative medium.

Periodic inspections of water circulation rate and bleed-off rate.

## Commissioning

Check that precooler is activated when system runs and outdoor air exceeds the minimum setpoint (typically 80F).

# Guideline TC16: Dedicated Outside Air Systems

## Recommendation

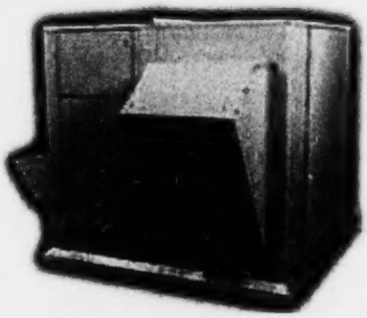
Install dedicated outside air ventilation systems to supplement or replace natural ventilation.

## Description

Dedicated outside air systems typically provide 100% outside air and deliver approximately 450 cfm to each classroom. The ventilation rate to other types of spaces should be provided according to the requirements of the California Building Code (Title 24).

Outside air systems can be designed with ducted return or with relief dampers to outdoors. Systems with ducted return air can recover exhaust heat with an air-to-air heat exchanger. Systems without a heat exchanger usually need some means to temper the outside air, especially during winter.

Small systems are available that can serve individual rooms, while larger systems can serve an entire building. With larger centralized ventilation systems, evaporative cooling or waste heat recovery may be economical for tempering outdoor air.



*Rooftop Air-to-Air Heat Exchanger (source: Lennox)*

*Small (Residential Style) Air-to-Air Heat Exchanger (source: Lennox)*

## Applicability

This design strategy applies mainly to classrooms, but can be used for other spaces where hydronic heating systems and natural ventilation are appropriate. This design strategy is not as applicable for spaces that have conventional air conditioning since outside air ventilation would be provided by the air conditioning system.

| Applicable Spaces | | Climates | | When to Consider | |
|---|---|---|---|---|---|
| Classrooms | ■ | South Coast | ■ | Programming | ☐ |
| Library | ■ | North Coast | ■ | Schematic | ■ |
| Multi-Purpose / Cafeteria | ■ | Central | ☐ | Design Dev | ☐ |
| Gym | ■ | Mountains | ■ | Contract Docs | ☐ |
| Corridors | ☐ | Desert | ☐ | Construction | ☐ |
| Administration | ☐ | | | Commissioning | ☐ |
| Toilets | ☐ | | | Operation | ☐ |
| Other | ☐ | | | | |

Dedicated outside air ventilation is especially appropriate in combination with baseboard or radiant heating systems, where a fan is not required for heating. However, even with forced air heating systems, a separate ventilation system may be appropriate if access to clean outdoor air is difficult from each individual room. In these cases, a central air handler can supply tempered ventilation air to each room, while each space heater recirculates indoor air and runs only when there is a demand for heating.

A dedicated ventilation system may also be appropriate where natural ventilation access is difficult due noise, extreme temperatures, dust, security, or lack of physical access to outdoors.

## Applicable Codes

Ventilation requirements can be satisfied by either mechanical or natural ventilation. See the Ventilation section of the Overview for more details.

## Integrated Design Implications

Special attention to controls is important to make sure that the ventilation system works together with the heating and/or cooling system. In addition, architectural coordination is important in locating relief dampers and in routing ventilation ducts.

## Costs

A dedicated outside air system will usually add cost to the overall HVAC system.

## Benefits

These systems will reduce energy costs in regions with cold and/or hot climates. In addition, they ensure proper ventilation, improving air quality and occupant well being.

## Design Tools

Most popular energy simulation programs, such as DOE2, do not have the capability to directly model dedicated outside air distribution systems. However, there are some tricks that can give an approximation of the energy use.

## Design Details

- In cold climates consider using an air-to-air heat exchanger to precondition outside air that is brought into the building.
- In hot climates, evaporation can be used to lower the temperature of air that is delivered to the space.
- Provide dampers that can automatically shut off ventilation air to each classroom. Consider using a motion sensor, that may already be installed for lighting, for control.
- Consider variable speed controls for central ventilation fans, so that airflow can be reduced when some rooms are unoccupied.
- Use gravity type or automatic relief dampers in each classroom, unless exhaust air is ducted to a central unit for heat recovery.
- Size the system to provide at least 15 cfm per person in classrooms and other spaces. If a classroom is expected to have 30 students, then 450 cfm should be delivered. If a classroom is expected to have 24 students, then 360 cfm is appropriate.
- Use filters to remove dust and other particles from outside air.

## Operation and Maintenance Issues

Replace filters on a regular basis.

## Commissioning

Provide documentation regarding the design intent to contractors and building operators to ensure that the system gets implemented properly.

Systems should be balanced so that adequate air is delivered to each classroom.

# Guideline TC17: Economizers

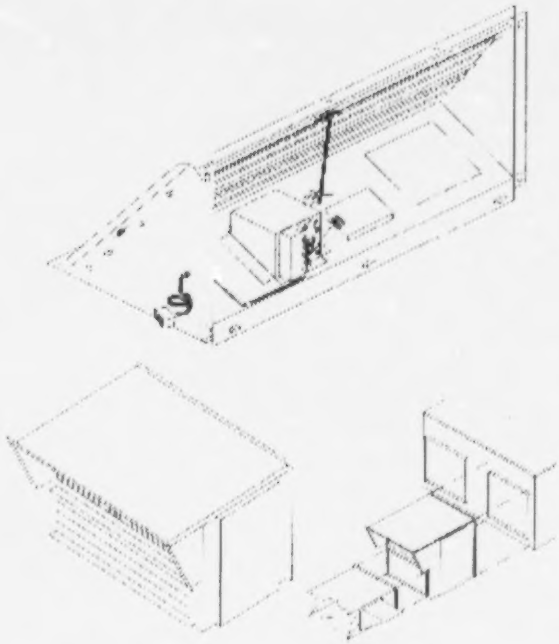
## Recommendation

Incorporate integrated economizer dampers and controls on HVAC systems that utilize return air. On units below 5 tons use non-integrated economizers with two-stage cooling controls

## Description

Economizers consist of three sets of dampers with interlinked controls: an exhaust damper which relieves space return air to offset ventilation air brought in; an outside air damper which controls the amount of ventilation air brought into the system; and a return damper which balances the return and outside air portions of the economizers. At low outside air temperature (below 60° to 65° F) the economizer dampers modulate to minimum ventilation position. This minimizes the heating load and protects the cooling coils from frosting at low loads. At high outside air temperature (above about 75° F), the economizer dampers return to this low ventilation position. At these temperatures the recirculated space air takes less energy to cool. Between these points, the economizer dampers modulate from minimum ventilation to 100 percent outside air, acting as a first stage of cooling in attempt to maintain the desired supply air temperature.

Integrated economizers allow simultaneous economizer and mechanical cooling. Non-integrated economizers first attempt to cool with outside air; if that doesn't satisfy the load, the economizer dampers return to minimum position and mechanical cooling is initiated.



Typical Economizer Equipment

| Applicable Spaces | | Climates | | When to Consider | |
|---|---|---|---|---|---|
| Classrooms | ■ | South Coast | ■ | Programming | ☐ |
| Library | ■ | North Coast | ■ | Schematic | ■ |
| Multi-Purpose / Cafeteria | ■ | Central | ■ | Design Dev | ■ |
| Gym | ■ | Mountains | ■ | Contract Docs | ☐ |
| Corridors | ■ | Desert | ■ | Construction | ☐ |
| Administration | ■ | | | Commissioning | ☐ |
| Toilets | ■ | | | Operation | ☐ |
| Other | ■ | | | | |

There are three common control methods:

- *Fixed temperature setpoint* economizers close to minimum position when outdoor air exceeds a fixed temperature setpoint, typically 72° to 74° F.
- *Differential temperature* economizers will operate whenever the temperature of the outside air is below the temperature of the return air.
- *Differential enthalpy* economizers compare the enthalpy of the outside air and return air streams and operate whenever the outside air has less heat content. Enthalpy economizers are most important in humid climates.

For moderate climates like much of California, economizers can be a significant means of minimizing space conditioning costs, because outside air will be within the comfort range for much of the school day throughout the year.

## Applicability

Economizers will be most effective on systems serving libraries, administration and other areas where occupant density is relatively low. In classrooms and assembly areas, where high occupant density will dictate a large minimum position on the outside air damper (30 percent or above), economizers controls are less likely to be cost effective.

On many existing systems, economizers can be added as a retrofit.

Economizers will not be as useful for spaces designed to use natural ventilation for cooling. In those cases, the cooling system may run only during hot periods when an economizer would be at minimum position anyway.

Economizers should not be installed in facilities that receive no maintenance because a failure can increase energy consumption.

## Applicable Codes

Title 24 requires integrated economizers on all systems providing more than 2,500 cfm of supply air and 75,000 Btu/hour of cooling capacity. No economizer is required for smaller units.

## Integrated Design Implications

Economizers are especially valuable with displacement ventilation systems because the higher supply air temperature allows an economizer to provide 100 percent of the cooling demand for a greater number of hours each year.

An economizer may be unnecessary in spaces with good natural ventilation design.

## Costs

The cost premium is $200 to $500 to add an economizer to a small packaged rooftop system.

## Cost Effectiveness

Economizers are very cost effective for spaces without natural ventilation.

| Costs | L | M | H |
|---|---|---|---|
| L | | ■ | |
| M | | | |
| H | | | |

Benefits

## Design Details

Economizers should be factory installed or specified to be factory-designed if they are to be field-assembled. Misapplication may cause coil and / or compressor damage.

Differential temperature control is recommended for most areas in California. However, in humid climates a differential temperature economizer could actually increase the system energy use by imposing a latent cooling load during economizer operation. A differential enthalpy economizer is ideal for humid areas, but enthalpy sensors require maintenance and can be unreliable. Therefore, a fixed temperature economizer with a setpoint around 72° is a good choice for coastal areas where mild temperatures are accompanied by fairly high humidity.

For retrofit applications care must be taken to protect the DX coil and compressor from damage during low loads. With existing DX systems, either non-integrated economizers should be installed or controls should be added to prevent compressor cycling and cutout on low evaporator temperatures. Economizer retrofits are applicable only to larger systems (above 7-1/2 tons).

## Operation and Maintenance Issues

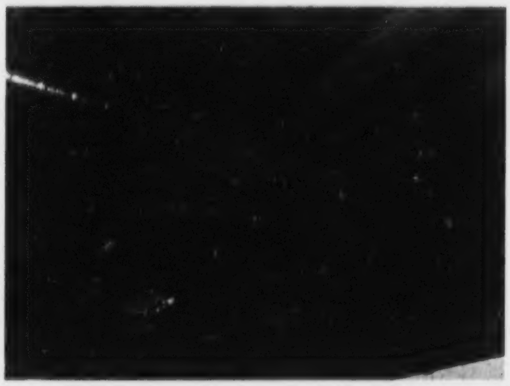
Clean and lubricate dampers and control linkages. Maintenance is critical to ensure that economizers work properly for the lifetime of the system.

### Commissioning

A functional test is critical to ensure that economizer controls are operating properly. With the system running during mild weather (outdoor cooler than indoor air), set the space thermostat to a low value to call for cooling and check that the outside air dampers are completely open. Then use a heat source, such as a hot-air gun, to warm the outside air temperature sensor and check that the outside air damper closes to its minimum position. Remove the heat source and check that the damper reopens (after the sensor has cooled).

For integrated economizers, also check that the outside air dampers remain completely open when the compressor is running and outdoor air is cool.

# Guideline TC18: Air Distribution Design Guidelines



## Recommendation

Design the air distribution system to minimize pressure drop and noise by increasing duct size, eliminating duct turns and specifying low-loss duct transitions and plenums. Use lowest possible fan speed that maintains adequate airflow. Pay special attention to the longest or most restricted duct branch.

| Applicable Spaces | | Climates | | When to Consider | |
|---|---|---|---|---|---|
| Classrooms | ■ | South Coast | ■ | Programming | ☐ |
| Library | ■ | North Coast | ■ | Schematic | ■ |
| Multi-Purpose / Cafeteria | ■ | Central | ■ | Design Dev | ■ |
| Gym | ■ | Mountains | ■ | Contract Docs | ■ |
| Corridors | ■ | Desert | ■ | Construction | ■ |
| Administration | ■ | | | Commissioning | ■ |
| Toilets | ■ | | | Operation | ☐ |
| Other | ■ | | | | |

## Description

Optimal air distribution system design is fairly complicated. An optimal design balances the need for comfort and low noise with overall HVAC system cost, energy cost, and long term maintenance and replacement costs. The are many factors affecting performance: diffuser type, number of diffusers, diffuser size, duct size, duct material, plenum type and size, fitting types, length of ducts, number of turns, type of turns, location of duct system (e.g. unconditioned attic or within conditioned space), priority for heating performance vs. cooling performance, and fan characteristics (pressure vs. airflow).

Due to the complexity of design, a detailed analysis is not common for small systems. Typically, designers and contractors rely on experience or rules of thumb in choosing system components. Even if design calculations are performed, however, decisions are not always the best in terms of energy efficiency and acoustic performance.

This guideline addresses small, constant volume duct systems that are common in California schools. It covers design targets for air velocities and pressure loss that help ensure an efficient and quiet system.

## Applicability

All ducted air systems.

## Applicable Codes

Title 24 requires that most ducts be insulated (depending on duct location).

In addition, individual HVAC systems with more than 25 hp of fans face efficiency limits of 0.8 watts/cfm for constant volume systems and 1.25 watts/cfm for variable volume systems.

## Integrated Design Implications

Air distribution design options are closely tied to the architectural design. The choice of duct type is often limited by space availability.

Ducts may be located outside, in unconditioned space, or within the conditioned space. The most efficient option is usually within conditioned space. More expensive sheet metal ducts are usually required, but they need not be insulated. If ducts are located in an unconditioned attic, then the roof must be insulated and/or equipped with a radiant barrier to reduce heat gain to the ducts. Outdoor ducts should not be used unless no other option is feasible.

Location of supply air outlets must be coordinated with lighting design (if located in ceiling) or space plan and furniture (for wall or floor outlets).

## Cost Effectiveness

Sometimes extra cost for low-loss fittings or larger ducts are necessary in order to achieve a high performance design. However, these costs can often be offset by carefully sizing the heating and cooling system to reduce overall system size. In addition, many air distribution improvements cost little or no extra, such as proper installation of flex duct.

## Design Tools

Numerous duct sizing computer programs are commercially available.

A common tool is a "Ductilator". A manual device used to calculate pressure loss for different types of ducts.

## Design Details

These guidelines are intended to cover typical small single zone systems. Additional criteria appropriate for multi-zone air distribution systems are not covered here.

### Airflow

**System cooling airflow.** Total system airflow should generally fall between 350 and 450 cfm/ton for systems with cooling. If airflow is greater, then condensation might blow off the cooling coil. If airflow is less than 350 cfm/ton, then the cooling capacity and efficiency drop. The capacity loss due to low airflow is worst in dry climates where latent cooling loads are low.

**System heating airflow.** For heating-only systems, a good target is 25 cfm per kBtu/h of heating capacity, providing about 105°F supply air. Heating airflow should not be lower than 15 cfm per kBtu/h because supply air temperature will exceed 135°F. If the airflow is low, then supply air will be too warm and air velocity too low, and poor mixing occurs in the room. Excessive airflow during heating creates more noise and can cause uncomfortable drafts.

**Airflow adjustment**. After system installation, airflow can be adjusted by either changing the fan speed or altering the duct system. To reduce airflow, lower the speed of the fan rather than install dampers. Try to use the lowest fan speed possible because fan energy consumption drops rapidly as fan speed decreases. If possible, specify a variable speed fan or multiple speed fan. To increase airflow, try to modify the duct system rather than increasing the fan speed. Possible measures include replacing the most restrictive ducts with larger sizes, improving duct transitions to reduce pressure loss, and eliminating duct turns or constrictions (especially in flex duct).

### Air velocity.

**Supply diffuser.** Velocity of air leaving supply air diffusers should generally not exceed 700 fpm to minimize noise. Most diffusers also have a minimum velocity for proper mixing and to avoid dumping cool air on occupants. Refer to manufacturers' guidelines for specific types of supply diffusers. When choosing diffusers based on NC noise rating, remember that manufacturers' data are usually at ideal conditions (long, straight duct attached to diffuser) and actual noise level is likely to be higher.

**Return grille.** The return air grille(s) must be larger than the total supply air diffuser area to avoid excessive noise. Air velocity should not exceed 300 fpm at the inlet.

**Duct.** Air velocity should not exceed 700 fpm in flex ducts and 900 fpm in sheet metal ducts. Higher flow creates excessive turbulence and noise. There is usually a practical lower limit to duct air velocity, where the duct becomes too large and expensive.

**Cooling coil.** Air velocity through the cooling coils should be minimized to reduce pressure loss. A good target is 300 fpm. However, designers seldom have a choice of coil area in small packaged

HVAC units, though it is possible to compare airflow and fan power data from different manufacturers to identify units with lower internal pressure loss.

### Duct type

**Flex duct.** Flexible ducts are widely used. They offer a number of advantages when properly installed but also have some disadvantages.

Flex ducts are most popular for their low cost and ease of installation. In addition, they attenuate noise much better than sheet metal ducts, offer lower air leakage, are usually pre-insulated, and provide some flexibility for future changes.

On the down side, pressure loss is greater in flex ducts, even when they are perfectly installed. They are also prone to kinking, sagging and compression, problems that further reduce airflow. And since they are flexible, flex ducts are usually installed with more turns than sheet metal ducts. Actual performance of flex ducts in the field is often poor due to these installation problems. As a final disadvantage, flexible ducts are typically warranted for only about 10 years and will need replacement more often than a sheet metal equivalent.

If flex duct is used, there are several important points to consider

- The duct must be large enough for the desired airflow (see table below).
- The ducts must be properly suspended according to manufacturer guidelines without compression or sagging.
- All ducts must be stretched to full length (see note in table below).
- Keep flexible duct bends as gentle as possible; allow no tight turns.
- Fasten all flex ducts securely to rigid sheet metal boots and seal with mastic (see Guideline TC19: Duct Sealing and Insulation),
- Limit duct lengths to no longer than about 20 feet (otherwise pressure loss may be too high).

| Flex Duct Diameter (inches) | Minimum Airflow (cfm) | Maximum Airflow (cfm) |
|---|---|---|
| 4 | 20 | 60 |
| 5 | 40 | 100 |
| 6 | 60 | 140 |
| 7 | 90 | 190 |
| 8 | 130 | 240 |
| 9 | 175 | 310 |
| 10 | 230 | 380 |
| 12 | 380 | 550 |

Table Notes

- Maximum airflow limits correspond to velocity of 700 fpm. Higher flows create turbulence and noise in flex ducts.
- Minimum airflow corresponds to a design friction rate of 0.06 inches/100 feet.
- The airflow values in the table assume that the flex duct is stretched to its full length. Airflow resistance increases dramatically if flex duct is compressed in length. Pressure loss doubles if the duct is compressed to 90% of its full length and triples if it is 80% compressed.

**Sheet metal duct.** The advantages to sheet metal ducts are lower pressure loss, longer life, greater durability and the potential for reuse or recycling at the end of the system's life. They are the only option for long duct runs or medium to high pressure duct systems. In addition, sheet metal ducts may remain exposed in conditioned spaces.

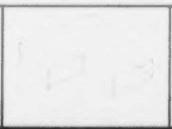
Disadvantages to sheet metal ducts are higher cost, higher sound transmission (sometimes they require noise attenuation measures that offset some of the pressure loss advantage), insulation requirement, and potentially greater leakage (though leakage is not an issue if they are properly sealed).

Round sheet metal ducts are preferred over rectangular when adequate space is available. Round ducts are likely to be quieter and cause less pressure loss for the same cross-sectional area. Rectangular ducts are susceptible to noisy drumming at high airflow.

### Reducing pressure loss

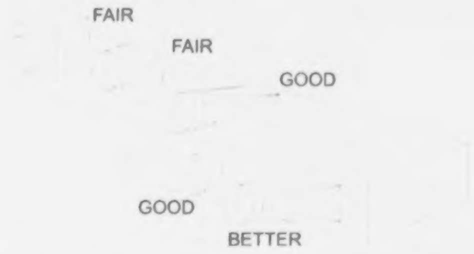
A number of measures may be taken to reduce pressure loss and improve airflow. Knowledge of the following simple principles may help the designer improve airflow:

- Air resists changing direction. The pressure drop of a turn can be reduced dramatically by smoothing the inside radius (the turn's outer radius does not matter as much). When possible, avoid sharp turns in ducts and never allow kinks in flexible ducts. Turning vanes are another option to reduce the pressure drop in a sharp turn.

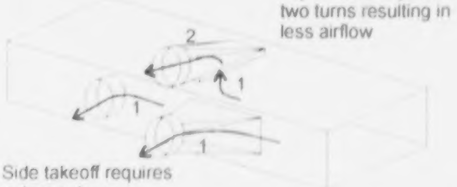
| | | |  | |
|---|---|---|---|---|
| | **BEST** | **GOOD** | **FAIR** | **POOR** |
| Relative Pressure Loss | 1.0 | X 1.3 | X 4.7 | X 13.0 |

Note: Total pressure loss calculated at 800 fpm air velocity.

- Airflow into branch ducts will be improved by using angled transitions (or conical taps) rather than typical straight connections. The angled transition is especially useful for critical branches that aren't getting enough air.



The fewer turns the better. For example, a side branch takeoff provides less flow resistance than a top branch takeoff because the top takeoff requires the air to turn twice.



Top takeoff requires two turns resulting in less airflow

Side takeoff requires only one turn

### Reducing noise

Noise reaching the space via the duct system is either transmitted from the air conditioning unit or generated by air turbulence within the air distribution system.

There are several measures to prevent sound transmission through the duct, such as sound absorbing duct liner, flex duct, duct turns, sound attenuators, and active noise canceling. The first three measures are the most feasible for small single zone systems because they are not prohibitively expensive and do not necessarily cause excessive pressure loss (small packaged systems usually don't have a lot of pressure to spare). Careful design is important to balance noise attenuation benefits vs. additional pressure loss.

Noise generation within the ducts or at grilles and diffusers can be controlled by limiting air velocity as described earlier in this guideline.

### Other Design Issues

Pay special attention to the duct branch with the greatest pressure drop, either the longest branch or the one with the most constricted turns. For longer branches, either larger duct size or low loss duct transitions will be required to achieve proper airflow.

Do not place balancing dampers directly behind diffusers. If they are necessary, then dampers should be located as close to the fan as possible to minimize noise and air leakage in the supply duct.

Connections to ceiling diffusers should have two diameters of straight duct leading into the diffuser. Otherwise noise and pressure drop can increase significantly.

Think twice before placing ducts in a hot attic. The roof can reach 150°F on a sunny day and the radiant heat load on the duct is significant. If ducts are above the ceiling, then insulation must be installed on or under the roof or a radiant barrier must be installed under the roof deck.

In many cases, if the pressure loss in the air distribution system can be reduced by as little as 0.15" SP, then fan speed can be reduced and fan power decreases significantly. In the case of a 3-ton rooftop packaged unit, energy savings can be $200 to $300 over a ten year period. Manufacturer's data for a typical 3-ton unit shows that the fan can supply 1100 cfm at 0.80 in. w.c. external static pressure if the fan is set to high speed. The fan can provide the same airflow at 0.65 in. w.c. at medium speed. Therefore, if the duct system is carefully designed and installed it may be possible to run at medium speed. The fan power then drops from 590 watts to 445 watts. For typical operating hours and electricity rates, the savings are about $30 per year.

## Operation and Maintenance Issues

Filters must be replaced regularly to maintain airflow.

## Commissioning

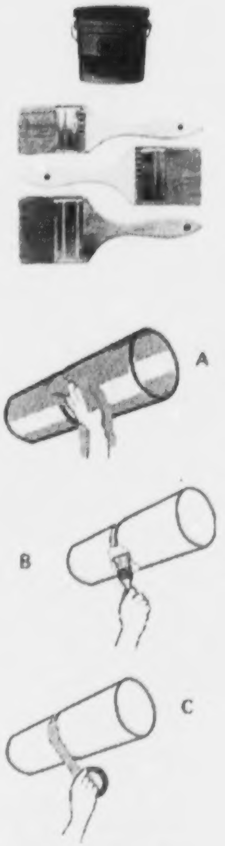
Measure supply airflow and external static pressure to compare to design values. If airflow is low then take measures to reduce restrictions in duct system rather than increasing fan speed.

## References / Additional Information

ASHRAE Handbook - 1997 Fundamentals. American Society of Heating, Refrigeration and Air Conditioning Engineers, Atlanta, Georgia.

*HVAC Systems Duct Design*, Sheet Metal and Air Conditioning Contractors National Association, Chantilly, Virginia.

# Guideline TC19: Duct Sealing and Insulation



## Recommendation

Create strong and long-lasting connections by mechanically fastening all duct connections and using mastic to seal connections and transverse joints (those perpendicular to airflow). If choosing pressure-sensitive tape as a sealant, then specify foil-backed tape with 15 mil butyl adhesive.

## Description

Duct leakage has a big impact on system efficiency and capacity. Studies of residential systems show that 20 to 30 percent loss is common. Similar problems exist in commercial duct systems.

Other studies have shown that some types of pressure-sensitive tape fail quickly in the field. Therefore, duct sealing systems must be specified carefully for longevity as well as strength and air-tightness.

Depending on duct location, insulation also plays a critical role in ensuring system efficiency and capacity. Title 24 requires a minimum of R-4.2 insulation on all ducts carrying conditioned air unless the ducts are located within conditioned space.

Supply and return air plenums must be sealed as well. These are usually the areas of greatest pressure in the air distribution system, and small holes create significant leaks.

*Mastic and Glass Fiber Tape for Duct Sealing*

*(source: RCD Corporation)*

| Applicable Spaces | | Climates | | When to Consider | |
|---|---|---|---|---|---|
| Classrooms | ■ | South Coast | ■ | Programming | ☐ |
| Library | ■ | North Coast | ■ | Schematic | ☐ |
| Multi-Purpose / Cafeteria | ■ | Central | ■ | Design Dev | ■ |
| Gym | ■ | Mountains | ■ | Contract Docs | ■ |
| Corridors | ■ | Desert | ■ | Construction | ■ |
| Administration | ■ | | | Commissioning | ☐ |
| Toilets | ■ | | | Operation | ☐ |
| Other | ■ | | | | |

## Applicability

All ducted air systems.

## Applicable Codes

Title 24 requires R-4.2 duct insulation unless the duct is completely within conditioned space. The standard also requires mechanical connections; tape or mastic alone is not allowed. In addition, sealing is required using mastic, tape, aerosol sealant or other system that meets UL 181. (Note, however, that a UL 181 rating should not be only consideration in choosing at duct sealing material; UL 181 does not test longevity of the sealing system.)

## Integrated Design Implications

Duct leakage problems can be avoided by placing ducts within the conditioned envelope or by eliminating them altogether (e.g. hydronic heating and cooling).

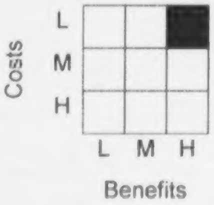
## Costs

Using mastic for duct sealing may increase material costs, but many find that labor costs drop compared to sealing with tape. Therefore, good duct sealing should not have a significant cost impact.

## Benefits

Careful duct sealing and insulation application will allow use of smaller cooling and heating equipment or at least allow the use of smaller safety margins in sizing calculations. Lower equipment cost may be a result.

Lower cooling and heating costs. Improved system performance and potentially better comfort. Reduction in infiltration and potential moisture problems within envelope components.



## Cost Effectiveness

Good duct sealing is almost always cost effective.

## Design Details

Do not rely on sealants, such as tape or mastic, to provide a mechanical connection. Specify screws, draw bands, or other mechanical fastening devices as appropriate for the duct type.

As a first choice, use mastic to seal all connections and transverse joints. Mastic is a liquid applied sealant that can also be used together with a mesh or glass fiber tape to provide added strength or to span gaps of up to about ¼ inch. Specify a mastic in a water-based solvent with a base material of polyester/synthetic resins free of volatile organic content.

If choosing pressure-sensitive tape as a sealant, then specify foil-backed tape with 15 mil butyl adhesive. Butyl tape has been found to have greater longevity in the field. Use of tape with rubber or acrylic adhesive should be avoided.

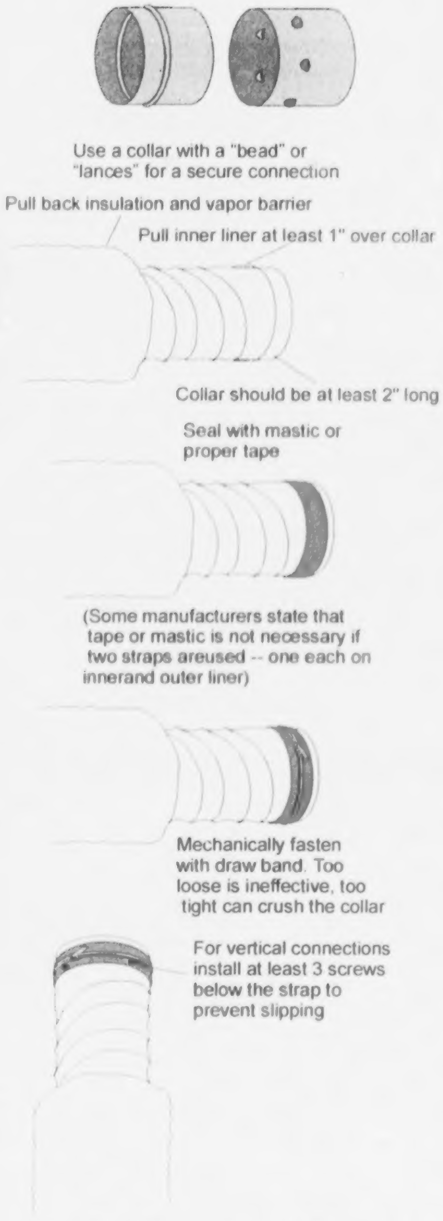
Flexible ducts must be mechanically fastened with draw bands securing the inner and outer plastic layers to the terminal boot. Specify that the draw bands be tightened as recommended by the manufacturer using an adjustable tensioning tool.

Seal both supply and return ducts and plenums.

## Commissioning

Inspect duct connections.

Test duct leakage.



Use a collar with a "bead" or "lances" for a secure connection

Pull back insulation and vapor barrier

Pull inner liner at least 1" over collar

Collar should be at least 2" long

Seal with mastic or proper tape

(Some manufacturers state that tape or mastic is not necessary if two straps areused -- one each on innerand outer liner)

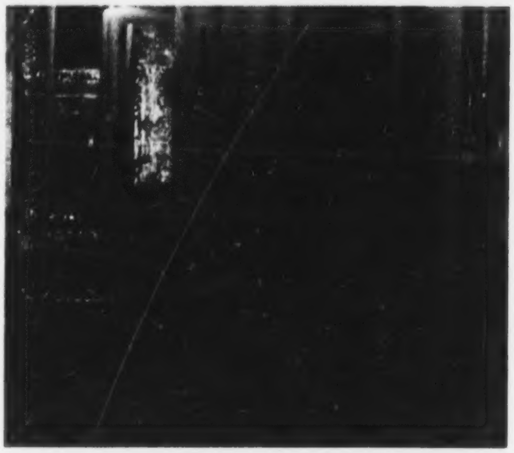
Mechanically fasten with draw band. Too loose is ineffective, too tight can crush the collar

For vertical connections install at least 3 screws below the strap to prevent slipping

*Flex Duct Connection and Sealing*

*(source: Manufactured Housing Duct Systems Guide to Best Practices)*

# Guideline TC20: Hydronic Distribution



**Applicable Spaces**
- Classrooms
- Library
- Multi-Purpose / Cafeteria
- Gym
- Corridors
- Administration
- Toilets
- Other

**Climates**
- South Coast
- North Coast
- Central Valley
- Mountains
- Desert

**When to Consider**
- Programming
- Schematic
- Design Dev
- Contract Docs
- Construction
- Commissioning
- Operation

## Recommendation

Consider using a variable flow system with variable speed drive (VSD) pumps. Insulate exposed hydronic heating/cooling piping. Make early decisions regarding the placement of heating/cooling components (radiators, ceiling panels, slab floors, boilers, chillers etc.). Use this information to create a system layout that minimizes piping material (pipes, bends, etc.) and head loss. When possible use larger pipe diameters and smaller pumping equipment to conserve energy.

## Description

Significant amounts of energy must be used to distribute water for heating and cooling. Proper design can result in substantial economic and energy savings. Unfortunately, hydronic distribution design is typically governed by past practices and not necessarily best practices. This makes the design process quick and easy, but not always the most economical or energy efficient. A hydronic distribution system consists of pipes, fittings, tanks, pumps, and valves.

## Applicability

Applicable in all areas.

## Applicable Codes

- Title 24 Section 123 details pipe insulation requirements.
- ASHRAE Standard 90.1 details requirements for various pump sizes.
- Consult Title 24 Mechanical Code regarding seismic support.

## Integrated Design Implications

Hydronic distribution is related to nearly all aspects of building design and construction. It is crucial that the HVAC piping contractor be involved throughout the design and construction process in order to maximize the efficiency and cost effectiveness of the hydronic distribution system. Simply laying out heating and cooling elements (baseboards, ceiling panels, chillers, boilers, etc.) in such a way that minimizes the required pipe material and maximizes straight-running pipe can save significant amounts of energy. Maximizing the amount of straight-running pipe also simplifies the insulating process.

## Costs

Initial cost for hydronic distribution depends on the quantity, size, and type of piping, valves, and pumps. Initial cost can be minimized through proper planning, sizing, and placement of each.

## Benefits

- A properly sized and installed system will provide quiet, efficient, and virtually maintenance free operation at minimal cost.
- Properly insulating all exposed piping will save energy and money. This can be cost effective at levels beyond code requirements.
- Increasing piping diameter significantly decreases the pumping power required. Head loss due to friction drops as nearly the fifth power with pipe diameter.
- Oversized piping allows for increases in load requirements from add-ons or renovations without complete system overhaul.

## Cost Effectiveness

When doing life cycle cost analysis compare incremental cost of increased pipe diameter to energy savings and savings from decreased size and cost of pumping system.

## Design Tools

- Use a CAD based program to design pumping layout.
- ASHRAE Handbook - Fundamentals outlines the process for determining pressure drop through piping layout.
- Pipe diameter selection involves balancing the following:
  - Location of pipe in the system
  - First costs of installed piping
  - Pump costs (capital and energy)
  - Erosion considerations
  - Noise considerations
  - Architectural constraints
  - Budget Constraints

## Design Details

### Piping Circuits

There are four general types of piping circuits, series, diverting series, parallel direct return, and parallel reverse return. The series types are one-pipe circuits and are the simplest and lowest cost design. Both the series and diverting series involve large temperature drops, however, only the latter allow for control of individual load elements.

The advantage of parallel piping circuits is that they supply the same temperature water to all loads. Direct-return networks are sometimes hard to balance due to sub circuits of varying length. Reverse-return networks are designed with sub circuits of nearly equal length. Parallel circuits are two-pipe systems.

### Valves

In general either two-way or three-way control valves are used to manage flow to the load. A two-way valve controls flow rate to the load through throttling, which causes a variable flow load response. Three-way valves are used in conjunction with a bypass line to vary flow to the load. Because the water that does not go to the load simply passes through the bypass line, three-way valves provide a constant flow load response. Significant energy savings can be realized when two-way control valves are used in conjunction with variable-speed drive (VSD) pumps

It is recommended that ball valves or butterfly valves be used for all isolation and balancing valves. These valves are reliable and offer a low pressure drop at a low cost.

**Pumps**

Centrifugal pumps are most commonly used in hydronic distribution systems. The use of VSD pumps can save significant amounts of energy and simplify the distribution system. Pump power falls at a cubed rate with speed and thus a VSD pump can be extremely cost effective for systems with significant load variations. Also, variable flow networks with VSD pumps use a simple two-way valve and do not require balancing valves. For systems that use supply air temperature reset controls, specify a clamp on the speed of the pump in order to avoid excessive energy use during system startup.

**Dual-Temperature Systems**

When a space requires both heating a cooling either a two-pipe system or four-pipe system can be used. In a two-pipe system all the loads must be either heating or cooling congruently. Two-pipe systems cannot be used when some spaces on the piping network need cooling while others need heating. Switching from one mode of operation to the other can be a fairly time consuming process. A four-pipe system is more complex, but it allows for heating and cooling on the same network and is more convenient than a two-pipe system when frequent changeovers are required.

**Expansion Chamber**

- Closed systems should have only one expansion chamber.
- Expansion Tanks open to the atmosphere must above the highest point in the circuit.

**Air Elimination**

Measures such as manual vents and air elimination valves should be taken to purge any gases from the flow circuit. Failure to do so can lead to corrosion, noise, and reduced pumping capacity.

**Insulation**

The insulation process becomes significantly easier when the piping network is laid out properly. Install all valves with extended bonnets to allow for the full insulation thickness without interference with valve operators. It may be cost effective to insulate pipes beyond code requirements.

**Water Treatment**

Care should be taken to avoid scaling and biological growth within the distribution system. Significant fouling resulting from either source is detrimental to system performance. The degree to which scaling can occur is dependent upon temperature, pH level, and the amount of soluble material present in the water. Scale formation can be controlled through several means including filtration and chemical treatments.

Biological growth is generally a larger problem for cooling systems. Heating systems typically operate at temperatures high enough to prohibit substantial biological growth. Chemical treatments with biocides such as chlorine and bromine have traditionally been used to control this growth. Alternatives to these chemicals include ozone and UV radiation. Ozone itself is toxic, however it readily breaks down into nontoxic compounds in the environment. UV radiation is completely nontoxic, but is only effective when turbidity levels are low. Mechanical methods such as blow downs can also be utilized to control fouling and decrease chemical use.

## Operation and Maintenance Issues

- Water quality should be checked on a regular basis to ensure fouling due to scaling or biological growth is not occurring.
- Periodically check piping insulation. Insulation adhesive can fail and expose piping.

- Check pressures, pumps, and valves on regular basis to ensure system is performing as intended.

### Commissioning

Commissioning should be performed throughout planning, design, construction, and operation to ensure proper installation, set-up, and integration with other facility components.

### References / Additional Information

*CoolTools: Chilled Water plant Design Guide* available from Pacific Gas and Electric
P.O. Box 770000, B32
San Francisco, CA 94177

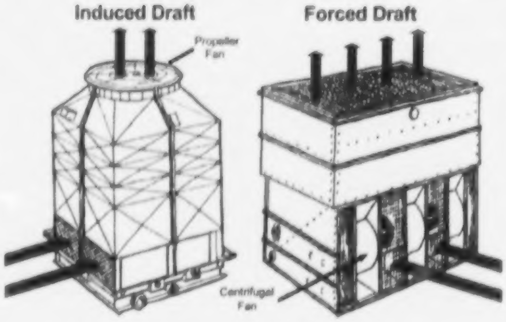
2000 ASHRAE Handbook - HVAC Systems and Equipment

HYDRONICS INSTITUTE
Berkeley Heights, New Jersey 07922
(908) 464-8200

# Guideline TC21: Chilled Water Plants

## Recommendation

Use high-efficiency, water-cooled, variable speed chillers. Use chiller heat recovery if there is a reliable hot water demand. Install oversized induced draft cooling towers with axial propeller fans. Use low approach temperatures and variable speed fan control.



*Cooling Towers*

| Applicable Spaces | | Climates | | When to Consider | |
|---|---|---|---|---|---|
| Classrooms | ■ | South Coast | ■ | Programming | ■ |
| Library | ■ | North Coast | ■ | Schematic | ■ |
| Multi-Purpose / Cafeteria | ■ | Central Valley | ■ | Design Dev | ■ |
| Gym | ■ | Mountains | ■ | Contract Docs | ■ |
| Corridors | ■ | Desert | ■ | Construction | ■ |
| Administration | ■ | | | Commissioning | ■ |
| Toilets | ■ | | | Operation | ■ |
| Other | ■ | | | | |

## Description

*Chillers.* There are two basic chiller classifications, air-cooled and water-cooled. Water cooled cost more (when considering the cooling tower and condenser water loop) but are more energy efficient. Within the classifications there are several chiller types. These include electric (centrifugal, reciprocating, screw or scroll), gas-fired (engine-driven or double effect absorption), and steam absorption.

*Towers.* The purpose of a cooling tower is to expose as much water surface area to air as possible to promote the evaporation of the water. Cooling towers come in a variety of shapes and configurations. A "direct" tower is one in which the fluid being cooled is in direct contact with the air. This is also known as an "open" tower. An "indirect" tower is one in which the fluid being cooled is contained within a heat exchanger or coil and the evaporating water cascades over the outside of the tubes. This is also known as a "closed circuit fluid cooler." The tower airflow can be driven by a fan (mechanical draft) or can be induced by a high-pressure water spray. The mechanical draft units can blow the air through the tower (forced draft) or can pull the air through the tower (induced draft). The water invariably flows vertically from the top down, but the air can be moved horizontally through the water (cross flow) or can be drawn vertically upward against the flow (counterblow).

## Applicability

Applicable for a small percentage of schools. Applicable in areas in need of significant amounts of chilled water and space cooling.

## Applicable Codes

Equipment should perform in accordance with efficiency guidelines in Title 24 and ASHRAE 90.1-1999. The energy performance requirements set forth by ASHRAE 90.1-1999 state that heat rejection devices must supply ≥ 38.2 gpm/hp for axial fan towers and ≥ 20.0 gpm/hp for centrifugal fan towers. EPA codes regarding chemicals (usually chlorine) used for cleaning. Methods using ozone for cleaning are also an option but this can lead to increased corrosion of internal systems.

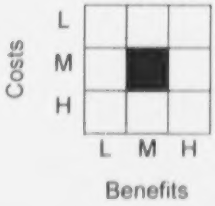
## Integrated Design Implications

Chiller and tower decisions are related to many aspects of building design and construction including space considerations, cooling/heating choices, and the hydronic distribution system layout. Tower performance is related to facility layout and orientation. The tower should be sited properly in order to minimize recirculation of saturated air.

The placement of chilled water plant components affects requirements of the hydronic distribution system. Try to make these decisions early in order to create a hydronic distribution layout that minimizes piping materials (pipes, bends, etc.) and head loss.

## Costs

Installed estimates for chillers between $575/ton and $781/ton depending on efficiency and drive choice. Installed tower cost estimates are between $133/ton and $178/ton.



## Cost Effectiveness

As a general rule, air-cooled chillers are more cost-effective if the chiller plant is less than 300 tons and water-cooled are more cost-effective above 300 tons. However, many factors affect operating costs for a chilled water plant, and the best choice of type, size, efficiency and controls is difficult to generalize. Most California facilities experience varying cooling loads over the course of the year, and a variable speed chiller will be cost effective. First cost premium when improving from an efficiency of 0.7 to 0.6 kW/ton is $70/ton. This number increases to $136/ton for variable speed chillers. Simple payback periods vary from 3 to 11 years.

Increasing size and efficiency of cooling tower is generally cost effective with a 4-7 year payback. Annual energy savings are between $0.01 and $0.04 per square foot. Incremental costs are between $0.08 and $0.12 per square foot depending upon climate.

## Design Tools

- CoolTools: Chilled Water plant Design Guide available from Pacific Gas and Electric.
- Gas Cooling Guide available from InterEnergy Software.
- The use of chillers with various efficiencies can be modeled using DOE2 and VisualDOE.

## Design Details

### Chiller Type.

The best choice among electric, gas, and steam chillers (or some combination thereof) is largely site specific. If a reliable source of free or very low cost steam is available on site, then steam absorption makes the most sense.

Gas versus electric or hybrid gas/electric will depend on utility rates. Gas-fired chillers can cost two times more than electrically driven machines and will require a larger cooling tower and condenser water pump. Gas engine chillers are more energy efficient than absorption machines and have high temperature heat readily available for recovery but are more maintenance intensive than absorption machines.

The most cost-effective type of electric chiller is primarily a function of chiller size. General decision guidelines are listed in Table .

*Table 28 -- Recommended Electric Chiller Types*

| Chiller Size | Recommendation |
|---|---|
| <= 100 tons | 1st choice: reciprocating<br>2nd choice: scroll<br>3rd choice: screw |
| 100 – 300 tons | 1st choice: screw<br>2nd choice: scroll<br>3rd choice: centrifugal |
| > 300 tons | 1st choice: centrifugal<br>2nd choice: screw |

### Number of Chillers

As a general rule:

- If the peak chilled water load is less than 300 tons then a single chiller is usually most economical.
- If the load is greater than 300 tons use two chillers. This offers better low load capability and operating efficiency and offers some redundancy should one of the chillers fail.

Having one smaller or pony chiller (as opposed to two or more equally size chillers) can improve part-load efficiency of the plant. However, some operators prefer if all the machines are the same size due to familiarity and parts interchangeability.

### Unloading Mechanism.

Centrifugal chillers typically use inlet vanes to control the chiller output at part-load. The use of hot gas bypass as a means to control the chiller at very low loads should be avoided, if at all feasible, as this strategy results in significant energy penalties. Using a variable speed drive instead of inlet vanes allows the compressor to run at lower speed at part-load conditions, thereby reducing the chiller kW/ton more than inlet vanes. The energy savings from a VSD chiller can be quite significant if the chiller operates many hours at low load. In order to capture the potential savings of VSD chillers it is important that the condenser water temperature is reset when ambient conditions are below design conditions. This can be accomplished either by using a fixed setpoint (e.g. 70°F) that is below the design condenser water temperature (e.g. 85°F) or using wetbulb-reset control, which produces the coldest condenser water the tower is capable of producing at a particular time. A gas engine chiller is also capable of unloading by decreasing engine speed.

### Chiller Efficiency.

The ratings in Table should be considered as upper bounds. Lower efficiencies are available and are often the lowest lifecycle cost option.

*Table 29 -- Recommended Chiller Rated Efficiency*

| Condenser Type | Compressor Type | Min Tons | Max Tons | Recommended kW/Ton | Recommended IPLV | Recommended C.O.P. |
|---|---|---|---|---|---|---|
| Water cooled | Scroll | 1 | 80 | 0.79 | 0.78 | |
| Water cooled | Screw | 1 | 150 | 0.76 | 0.70 | |
| Water cooled | Screw | 151 | 300 | 0.72 | 0.70 | |
| Water cooled | Screw | 301 | & up | 0.64 | 0.61 | |
| Water cooled | Reciprocating | 1 | 80 | 0.84 | 0.75 | |
| Water cooled | Reciprocating | 81 | & up | 0.82 | 0.75 | |
| Water cooled | Gas Engine | 501 | 2000 | | | 1.80 |
| Water cooled | Absorption (SE) | 150 | 1000 | | | 0.65 |
| Water cooled | Absorption (DE) | 150 | 1000 | | | 1.00 |
| Water cooled | Centrifugal | 1 | 150 | 0.62 | 0.62 | |
| Water cooled | Centrifugal | 151 | 300 | 0.60 | 0.61 | |
| Water cooled | Centrifugal | 301 | & up | 0.56 | 0.56 | |
| Air cooled | Scroll | 1 | 80 | 1.25 | 1.10 | |
| Air cooled | Absorption (SE) | 1 | & up | | | 0.60 |
| Air cooled | Screw | 1 | & up | 1.21 | 1.00 | |
| Air cooled | Reciprocating | 1 | & up | 1.15 | 1.15 | |
| Air cooled | Centrifugal | 1 | & up | 1.30 | 1.30 | |

### Heat Recovery Chiller.

Heat rejected from the condenser of a chiller can be recovered and used to drive a desiccant system or for preheating domestic hot water by routing the condenser water through a double-wall heat exchanger that is either an integral part of a storage tank or is remotely located with a circulation pump to the storage tank. Heat recovery chillers are typically used only for a portion of the total cooling load, because of the need for to match hot water load and cooling load and because of the lower efficiency of heat recovery chillers. Heat recovery chillers are not typically piped in parallel with other chillers but rather are either piped for "preferential" loading or in series with other chillers, allowing the cooling load on the heat recovery chiller to be matched to the hot water load. Waste heat can also be recovered from the engine jacket and exhaust of gas engine driven chillers.

The energy savings from chiller heat recovery are reduced when using economizers (air-side or water-side) because chillers are often not needed when the weather is mild or cold. Chiller heat recovery cannot eliminate the need for a DHW boiler but it can eliminate the need for some of the cooling towers at a site.

### Chiller Staging.

For a plant composed of single-speed chillers, control systems should be designed to operate no more chillers than required to meet the load. A plant composed of variable-speed chillers should attempt to keep as many chillers running as possible, provided they are all operating at above approximately 20% to 35% load. For example, for the typical variable-speed chiller plant, it is more efficient to run three chillers at 30% load than to run one chiller at 90% load. The use of hot gas bypass at very low loads should be avoided, if at all feasible, as this strategy results in significant energy penalties.

### Tower Fan Speed Control.

Two-speed (1,800 rpm/900 rpm) or variable speed fan control is always more cost effective than single speed fan control. For plants with multiple towers or multiple cells, provide two- or variable-speed control on all cells, not just the "lead" cells. The towers are most efficient when all cells are running at low speed rather than some at full speed and some off. For instance, two cells operating at half speed will use about 15% of full power compared to 50% of full power when one cell is on and the other is off.

**Tower Over Sizing.**
The tower and fill can be oversized to reduce pressure drop, thereby allowing the fan to be slowed down, which reduces motor power. Tower heat transfer area should be oversized to improve efficiency to at least 60 to 80 gpm/HP at CTI conditions.[27] There will be some added cost to oversize the tower and to accommodate the larger tower footprint and weight but it should be outweighed by energy savings.

A larger tower can also produce cooler water, allowing chillers to run more efficiently. Selecting towers for a 4 or 5 degree approach will generally be cost effective relative to a more typical 10 degrees. Cooling towers are available with as low as 3 degree approach temperature, but the tower cost increases as the degree of approach drops. A life cycle cost analysis should be performed to compare the extra cost to the energy impact on tower, chiller and pumps.

**Tower Performance.**
The performance of a cooling tower is a function of the ambient wet bulb temperature, entering water temperature, air flow and water flow. The dry bulb temperature has an insignificant effect on the performance of a cooling tower. "Nominal" cooling tower tons are the capacity based on a 3 gpm flow, 95°F entering water temperature, 85°F leaving water temperature, and 78°F entering wet bulb temperature. For these conditions the range is 10°F (95-85) and the approach is 7°F (85-78).

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[27] Tower efficiency (as defined in ASHRAE Standard 90.1-1999) is the ratio of the maximum tower flow rate (gpm) to the fan motor horsepower (hp) at standard CTI rating conditions (95°F to 85°F at 78°F wet bulb). Standard efficiency is about 35-40 gpm/HP efficiency

*Table 30 -- Cooling Tower Design Considerations*

| | Energy | Noise | Height | Chiller Fouling | Cost | Application |
|---|---|---|---|---|---|---|
| Packaged induced draft, axial fan | Lower | Higher | Higher | Higher | Medium | Best for most plants |
| Field-erected induced draft, axial fan | Lowest | Higher | Higher | Higher | Higher | Very large plants |
| Forced draft, centrifugal fan | Higher | Lower | Lower | Higher | Lower | Best if noise or height constrained or large external static pressure (e.g. tower located indoors) |
| Closed circuit evaporative cooler, axial fan | Higher | Higher | Higher | Lower | Highest | Appropriate for heat pumps, not most chillers |
| Closed circuit evaporative cooler, centrifugal fan | Highest | Lower | Lower | Lower | Highest | Appropriate for heat pumps, not most chillers |
| Spray towers | Lowest | Lowest | Higher | Higher | Lowest | Seldom used due to high maintenance and variable condenser water flow |

### Operation and Maintenance Issues

Periodic blow downs and scrubbing of cooling towers must be performed to avoid scaling of internal systems and biological growth. The condition of cooling tower fill is critical to performance. It should be inspected every year and the chemistry of the tower water should be maintained to minimize fouling.

### Commissioning

In order for chillers to operate efficiently, they must be properly commissioned. Part of this process is making sure that sensors (such as chilled water flow, chilled water supply and return temperatures, and chiller electric demand), are specified and properly calibrated. Sensor data should be permanently stored by the EMS system and easily visualized graphically. Not only is this data valuable for insuring that the design intent is met in the construction process, but also for maintaining energy efficiency over the life of the chiller. For example, by monitoring the approach temperatures in the condenser and evaporator heat exchangers (as the heat exchanger surface becomes fouled, the approach temperature increases) maintenance can be scheduled when needed, as opposed to too often, which wastes maintenance resources, or too infrequently, which wastes energy. A detailed account of commissioning issues specific to chilled water plants can be found in the CoolTools design guide.

### Examples

- Ventura County, Todd Road Jail uses an energy efficient electric chiller rated at 0.55 kW/ton. Ventura County, 805-654-3091
- At the Santa Ana Police Facility, condenser water from a small chiller preheats water using a plate and frame heat exchanger that replaces the cooling tower. The system provides about 10 degrees of heating. (714) 245-8061

**References / Additional Information.**

*CoolTools: Chilled Water plant Design Guide* available from Pacific Gas and Electric
P.O. Box 770000, B32
San Francisco, CA 94177

InterEnergy Software, www.interenergysoftware.com

COOLING TOWER INSTITUTE
STD-201 (November 1996) Certification Standard for Commercial Water Cooling Towers
Available from: Cooling Tower Institute
Post Office Box 73383
Houston, Texas 77273(281) 583-4087

# Guideline TC22: Hot Water Supply

## Recommendation

Consider high efficiency gas-fired boilers for space heating and domestic hot water. If demand is large and variable install several smaller modular boilers instead of one large unit. If conditions permit augment boiler with solar thermal system and/or recovered thermal energy.

| BOILER Applicable Spaces | | Climates | | When to Consider | |
|---|---|---|---|---|---|
| Classrooms | ■ | South Coast | ■ | Programming | ■ |
| Library | ■ | North Coast | ■ | Schematic | ■ |
| Multi-Purpose / Cafeteria | ■ | Central Valley | ■ | Design Dev | ■ |
| Gym | ■ | Mountains | ■ | Contract Docs | ■ |
| Corridors | ■ | Desert | ■ | Construction | ■ |
| Administration | ■ | | | Commissioning | ■ |
| Toilets | ■ | | | Operation | ■ |
| Other | ■ | | | | |

| SOLAR Applicable Spaces | | Climates | | When to Consider | |
|---|---|---|---|---|---|
| Classrooms | ■ | South Coast | ■ | Programming | ■ |
| Library | ■ | North Coast | ■ | Schematic | ■ |
| Multi-Purpose / Cafeteria | ■ | Central Valley | ■ | Design Dev | ■ |
| Gym | ■ | Mountains | ■ | Contract Docs | ■ |
| Corridors | ■ | Desert | ■ | Construction | ■ |
| Administration | ■ | | | Commissioning | ■ |
| Toilets | ■ | | | Operation | ■ |
| Other | ■ | | | | |

## Description

*Boilers.* Boilers are pressure vessels that transfer heat to a fluid. They are constructed of cast-iron, steel, aluminum, or copper. There are two basic types, fire-tube and water-tube. Fire-tube configurations heat water by passing heated combustion gases through conduit that is submerged in the water. This system generally uses natural gas or oil as the combustion fuel. Water-tube configurations pass water in pipes through the heated combustion gases and can use natural gas, oil, coal, wood, or other biomass. The air needed for combustion can be supplied by either mechanical or natural means. Hot water boilers are generally classified as either low temperature, less than 250 °F, or high temperature, 250-430 °F and are rated by their maximum working pressure. All boilers systems have the following components in common:

- Fuel Supply: natural gas, oil, wood, or other biomass.
- Burner: The burner injects a fuel-air mixture in the combustion chamber.
- Combustion chamber: Location in boiler where combustion occurs.
- Heat exchange tubes: Tubes within the boiler that contain water for a water-tube model and combustion gases in a fire-tube unit.
- Stack: The stack is the chimney through which combustion gases pass into the atmosphere.
- Hydronic distribution system: Supplies feed water to the boiler and distributes hot water to the facility.

*Solar Thermal.* A solar thermal system can be either direct or indirect and classified as either active or passive. A direct system heats water directly in solar collectors. An indirect system uses a working fluid (usually a glycol-water mixture) in conjunction with a heat exchanger to increase the water temperature. Direct systems contain less elements and are cheaper, however they are prone to freezing and cannot be used in all climate zones without drain back systems. Indirect systems use an antifreeze mixture and can be used in any climate zone. Active and passive refers to the method by which fluid reaches the collector. If the fluid moves through natural convection the system is termed passive and if pumps are used it is active. Solar thermal systems consist of the following elements:

- Solar Radiation Collector: Collects solar radiation for heating.

- Heat Exchanger: A heat exchanger is used in an indirect system to pass heat from the working fluid to the water supply.
- Hydronic distribution system: Supplies water to the collector for direct systems and to the facility for both direct and indirect systems.
- Storage Tank: Stores heated water for facility use or for boiler feed water supply.

## Applicability

Applicable in any situation where a significant amount of space heating and/or water heating are required. A solar thermal water heating system has the potential to be the main hot water source in some situations. For example, an elementary school in the desert could easily meet most of its hot water needs through solar energy utilization. It most areas it could at least augment the boiler system.

## Applicable Codes

- Title 24 Section 123 details pipe insulation requirements.
- Title 24 Section 113 requires the following regarding hot water storage tanks:
  - At least R-12 external insulation; or
  - Combined external and internal insulation of R-16; or
  - Less than 6.5 but/hr/ft$^2$ of heat loss based on a water-air temperature difference of 80°F.

### Boilers

- Title 24 Section 112 specifies the minimum efficiency requirement for boilers to be 80-83% depending upon combustion fuel and size.
- The boiler should comply with the ASME Boiler and Pressure Vessel Code. This includes codes regarding suggested maintenance.
- Stack placement should adhere to ASHRAE 62 standards. Stack emissions must conform to requirements set forth by the Clean Air Act under jurisdiction of the applicable air quality district.

### Solar Thermal

- Solar specific components should be certified by the Solar Rating and Certification Corporation.

## Integrated Design Implications

A certain amount of hot service water will always be needed for restroom facilities. Any additional need is dependent upon the choice of space heating system (air or hydronic) and whether or not the building design includes a swimming pool and/or commercial sanitation and food preparation equipment. The actual heating load is dependent upon climate and decisions regarding fenestration, hydronic distribution, building envelope, indoor equipment, and building orientation. The placement of boiler or solar thermal components affects requirements of the hydronic distribution system. Try to make these decisions early in order to create a hydronic distribution layout that minimizes piping materials (pipes, bends, etc.) and head loss.

If a central cooling plant is being considered for the facility the possibility of using recovered thermal energy should be considered. Using this technique could affect many aspects of design including chiller choice.

### Solar Thermal.

A radiant slab heating system works extremely well with solar thermal water heating. Solar thermal systems can generally achieve the low inlet temperatures (90-120°F) required by a radiant slab system.

Because the performance of a solar thermal system is dependent upon the weather, it works best when used in conjunction with another heating system. Depending upon the situation, the solar system can be the primary heat source or can be used to augment and increase the efficiency of a boiler system. The increased efficiency is accomplished by preheating boiler feed water with solar thermal energy.

The use of a solar thermal system must be addressed early in the planning stages, as its viability is highly dependent upon available roof space and building orientation. It is also important to plan the placement of any other roof systems to avoid shading by packaged HVAC systems, stacks, walls, etc.

## Costs

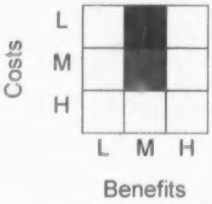
### Boilers

- Total installed costs between \$35/kBtuh and \$52/kBtuh depending on efficiency.
- Some maintenance costs as well but they can save huge future costs.

### Solar Thermal.

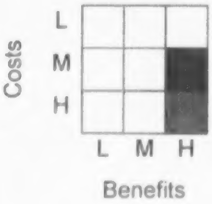
Initial costs are higher than that for a boiler system. Most systems cost between \$30 and \$90 per square foot of collector area. Maintenance costs are low and fuel expenses are zero.

## Benefits



### Boiler

- Longer life span than standard storage water heaters.
- More efficient than furnace.
- Gas boilers burn significantly cleaner than oil, coal, and wood fired units.



### Solar

- Free fuel.
- Don't have to worry about changing fuel prices.
- Non-polluting. No fumes means healthier for students and teachers. No operational greenhouse gas emissions.
- Great for teaching. The system itself can be a topic in science classes.

## Cost Effectiveness

### Boiler.

Condensing boilers cost from 30 to 60 percent more than standard units up to 500 kBtu/hr. Incremental costs for more efficient boilers range from \$0.23 to \$0.35 per square foot depending on climate. The more efficient boilers realize simple payback period of five to ten years.

### Solar Thermal.

The initial cost for solar thermal systems is somewhat more than boilers. However, the fuel is free and thus the system will eventually pay for itself. For a slab system it may be the more cost effective option since it is heating to its maximum while a boiler would need to be run at a lower, less efficient setting. The cost effectiveness of a solar system varies from site to site, as the payback period is dependent upon climate and available solar radiation. Solar thermal systems will be most cost effective in schools with substantial summer occupancy as this is the time of greatest available solar radiation.

## Design Tools

**Boiler.**
The use of boilers with various efficiencies can be modeled using DOE2 and VisualDOE.

**Solar Thermal.**

- The Transient System Simulation Program (TRNSYS) developed by the University of Wisconsin-Madison Solar Energy Lab is capable of modeling entire solar water heating systems.
- The National Renewable Energy Lab has extensive data regarding annual totals of solar radiation for different cities in California.
- *Solar Engineering of Thermal Processes* by John Duffie and William Beckman is a great resource for solar energy applications.

## Design Details

**Boiler**

- Large systems between 75 and 85% efficient.
- New condensing gas-fired boilers are up to 96% efficient.
- Boiler Energy saving add-ons:
- Economizers preheat feed water with energy from stack gases before it goes to the boiler.
- Air preheaters preheat the air that is mixed with the fuel for combustion leaving more energy to heat the water.
- Turbulators increase the convective heat transfer rates in fire-tube boilers by inducing higher levels of turbulence.
- Oxygen trim controls measure and adjust oxygen levels in the inlet air before combustion.
- Boiler reset controls automatically change the high-limit set point based on changes in outdoor temperatures.
- Since boilers are generally most efficient at their rated capacity it is better to have several smaller boilers rather than one large unit that is rarely used at its most efficient setting.
- Condensing boilers produce acidic condensate that is corrosive to some materials such as steel or iron. Make sure to account for proper condensate drainage and follow manufacturers specifications for exhaust flue design if specifying a condensing boiler.

**Solar Thermal.**
System requires use of a differential thermostat to ensure heat is not being dumped to the collectors. The most important element of a solar thermal system is the solar collector. Solar collectors can be either fixed or track the sun. The latter is generally more expensive and is saved for high-temperature applications. Fixed collectors should be oriented facing south and tilted based on seasonal load. A good rule of thumb is to use the location's latitude as the tilt angle with respect to the horizontal.

- Flat-plate collectors consist of a metal frame box containing a layer of edge and backing insulation, an absorber plate with parallel piping, and glazing. The absorber plate is generally constructed of copper or aluminum with a high absorbtance coating . The glazing layer reduces convective and radiation heat loss and involves one or more sheets of glass. Solar thermal systems with flat-plate collectors are very common.
- Integral Collector Storage (ICS) systems use storage tanks themselves as solar collectors. The tanks are painted black and are set on the roof alone or in insulating boxes with transparent covers angled south. ICS systems are applicable only in mild climates, as freezing and significant heat loss become an issue in colder regions. This system is very simple and cost-effective.

- The evacuated tube collector is a long and thin version of a flat-plate collector where the box has been substituted by a glass tube and the insulation by a vacuum. These collectors are extremely efficient but are fragile and expensive.
- Concentrating collectors use a curved surface to reflect and concentrate the solar radiation onto a pipe containing fluid. These collectors are generally used for high-temperature applications and almost always configured to track the movement of the sun.

## Operation and Maintenance Issues

### Boiler.

Performing basic operating and maintenance practices on boilers is very important. Regular inspection of boiler system components ensures safe and efficient operation. Proper maintenance can lead to energy savings of 10 to 20%, reduce harmful emissions, and increase the lifespan of the system.

- Fire side maintenance:
- Minimize excess combustion air and monitor stack gas $O_2$ and $CO_2$ to ensure proper percentages. Too little air can cause increased CO and particulate emission, while too much can lower efficiency.
- Clean heat transfer surfaces.
- Water Side Maintenance
- Perform regular 'blow downs" to reduce the level of Total Dissolved Solids (TDS) in the system. High TDS levels cause pipe fouling that reduces the heat transfer rate and increases the pressure drop.
- Insulate boiler walls and piping.

### Solar Thermal

- Collector glass should be cleaned regularly to ensure maximum efficiency.
- Direct systems must be drained when freezing conditions exist.

## Commissioning

### Boiler.

Commissioning should be performed to ensure proper installation and operation. It is particularly important to properly train maintenance operators. The safety and efficiency of a boiler system is highly dependent upon the duties performed by boiler personnel.

### Solar Thermal.

Commissioning is important for solar thermal systems because the general contractor may not be familiar with them. Solar systems must be considered whenever rooftop decisions are made. The efficiency of the system is wholly dependent upon collector orientation and minimizing shading. It is important to have a solar expert on hand whenever the system is being considered. Even for such things as storing collectors before installation. (Some collectors can be damaged if stored in the sun without fluid passing through them.)

## Examples

### Boiler

The Todd Road Jail installed a 90% efficient pulse boiler to provide space conditioning and hot water for a laundry facility. Ventura County, (805) 654-3091.

The Rio Consumnes Correctional Facility in Sacramento County also uses a natural gas fired pulse boiler. Rio Consumnes Correctional Facility, (916) 874-7469

**Solar Thermal**

Albion Elementary School, Near Mendocino. Hot water supplied by 22 panel solar thermal system.

UC-Santa Cruz Student Housing, Santa Cruz, California.

Newport Coast Elementary School uses a solar thermal water heating system to preheat kitchen water.

## References / Additional Information

**Boiler**

ASME. 1998. *Boiler and Pressure Vessel Codes.*
American Society of Mechanical Engineers, New York

The Fulton Companies
3981 Port Street, Box 257
Pulaski, NY, USA 13142-0257
Telephone: (315) 298-5121
Fax: (315) 298-6390
www.fulton.com

DONLEE Technologies Inc.
693 North Hills Road
York PA USA 17402-2211

**Solar Thermal**

Federal Energy Management Program
http://www.eren.doe.gov/femp/

Energy Efficiency and Renewable Energy Network
http://www.eren.doe.gov

Beckman, J.A. and Beckman, W.A., *Solar Engineering of Thermal Processes.* Wiley-Interscience, New York. 1991.

2000 ASHRAE Handbook. HVAC System and Equipment

2000 AHRAE Handbook. HVAC Applications

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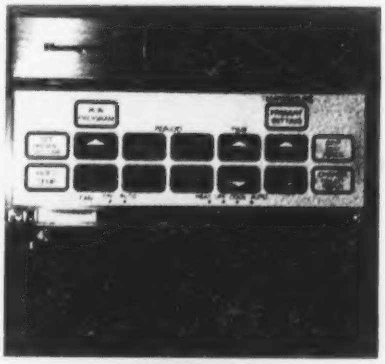
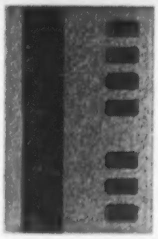
# Guideline TC23: Adjustable Thermostats





**Recommendation**
Specify thermostats or temperature sensors that will allow classroom teachers control over comfort conditions in their classroom including temperature (within limits) and noise.

**Description**
Teachers find it helpful to have control over conditions in their classrooms because different conditions may be appropriate at different times. For example, cooler temperatures may be appropriate after recess or for a more active group. It may be appropriate to turn off mechanical ventilation for certain activities requiring acute hearing or when windows are open. Where an Energy Management System is not used for temperature control, programmable thermostats can allow implementation of energy saving and comfort enhancing measures, but only if programmed and maintained properly. Care should be taken to select a model that is very easy to program. Otherwise, it is likely to be overridden or set for continuous operation.

| Applicable Spaces | | Climates | | When to | |
|---|---|---|---|---|---|
| Classrooms | ■ | South Coast | ■ | Programming | ☐ |
| Library | ■ | North Coast | ■ | Schematic | ☐ |
| Multi-Purpose / Cafeteria | ▨ | Central | ■ | Design Dev | ■ |
| Gym | ▨ | Mountains | ■ | Contract Docs | ■ |
| Corridors | ☐ | Desert | ■ | Construction | ■ |
| Administration | ■ | | | Commissioning | ■ |
| Toilets | ☐ | | | Operation | ■ |
| Other | ░ | | | | |

**Applicable Codes**
Title 24 requires set back thermostat, time of day control and over ride. A programmable thermostat is a cost effective way to satisfy these requirements.

**Costs**
$50 - $200 premium for programmable thermostat

**Benefits**
Improved comfort and sense of control may foster a better attitude and teaching environment. Some energy savings may be realized due to stopping mechanical ventilation when windows are open. Service requests may be reduced compared to situations where teachers must request a set point change from O&M personnel. Programmable thermostats replace time clocks, eliminating associated first and maintenance costs.

**Cost Effectiveness**
Programmable thermostats are highly cost effective. For a relatively small incremental increase over conventional thermostats, a carefully selected and programmed model will provide teachers with control over their classroom environment while combining time of day and override functions. DDC system sensors with adjustable set point have a greater incremental cost impact over plain sensors, but the benefits of giving teachers control should not be underestimated.

| Costs | L | M | H |
|---|---|---|---|
| L | ▨ | ■ | |
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| H | | | |

Benefits

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### Design Details

- Specify programmable thermostats for control, adjustment, time-clock and override functions when no DDC system will be used for temperature control.
- Sensors with set point control and fan/unit on/off control should be specified for temperature control of classrooms using a DDC system. Also specify limits within which the set point may be varied and the time period after which an overridden value or state will revert to the standard "automatic" or default value or state.
- If it is felt that locking thermostat covers are necessary, provide a means for access by faculty.
- Place the thermostat on an interior wall in a location out of direct sun and away from heat sources such as copiers or computers. A point close to the return air or exhaust air inlet is often a good choice.

### Operation and Maintenance Issues

Faculty may require repeated training on programmable thermostat operation. Unlike DDC system temperature sensors with adjustable set point, which can be programmed to revert to standard operation after a specified period, programmable thermostats may allow the HVAC system to be switched (rather than over ridden) off. This can defeat morning warm up, resulting in comfort problems and complaints. Specify simplified 1-page instructions be provided by installing contractor and kept on file at school office with copies distributed to teachers for adjustable sensors or programmable thermostats. Programmable thermostats may require periodic replacement of back-up battery.

### Commissioning

Proper functioning of any thermostat or temperature sensor must be verified prior to acceptance of the installation. Programmable thermostats and Temperature sensors with adjustable set point necessitate a slightly more involved verification procedure.

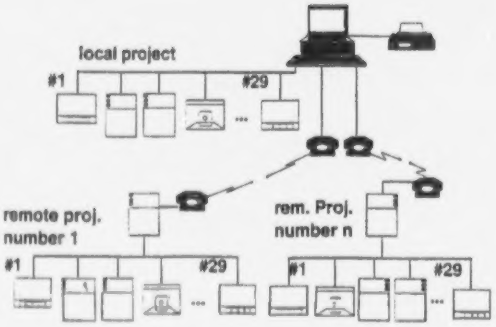
### Example(s)

New Orchard School, San Jose, CA – Elementary.

# Guideline TC24: EMS/DDC

## Recommendation

Use a DDC system to integrate multiple components of HVAC and other building systems and manage them from a single (local and/or remote) location.



| Applicable Spaces |  | Climates |  | When to Consider |  |
|---|---|---|---|---|---|
| Classrooms | ■ | South Coast | ■ | Programming | ■ |
| Library | ■ | North Coast | ■ | Schematic | ■ |
| Multi-Purpose / Cafeteria | ■ | Central | ■ | Design Dev. | ■ |
| Gym | ■ | Mountains | ■ | Contract Docs | ■ |
| Corridors | ■ | Desert | ■ | Construction | ■ |
| Administration | ■ |  |  | Commissioning | ■ |
| Toilets | ■ |  |  | Operation | ■ |
| Other | ■ |  |  |  |  |

## Description

Automatic control of multiple pieces of HVAC equipment and other systems may be integrated using computerized systems known variously as DDC (Direct Digital Control), EMS (Energy Management Systems), EMCS (Energy Management and Control Systems), BMS (Building Management Systems) etc. The added expense and complexity may be justified by the equipment optimization and increased convenience of maintenance possible with such a system.

DDC systems generally perform three functions: equipment on/off control, space temperature control and equipment status monitoring. A single system can control lighting, security, central plant equipment and space conditioning equipment. Systems may be specified to allow local override and temperature adjustment at selected space temperature sensors. Graphical user interfaces may be custom configured with different levels of access to allow limited adjustment of schedules and other system parameters by various personnel. While a DDC system will permit the implementation of energy and cost saving measures not otherwise possible, the advantages will only be realized if the system is initially programmed correctly and checked periodically by adequately trained personnel.

DDC systems consist of individual controllers that communicate with one another over a network linked by two-conductor cable or other means. Each controller is wired directly to relays, valve and damper motors, temperature sensors, etc., in order to control and monitor specific equipment. Controllers generally require line voltage power to control panels containing one or more controllers. All other wiring is generally low voltage. The systems may connect directly, via LAN or MODEM to a desktop or laptop computer for monitoring and adjustment. Additional software is generally required on this computer is a "user friendly" graphical interface is desired. Systems may be programmed to retain and plot temperature and other status data for performance analysis over limited periods, but retention of historical data requires optional software and additional storage media.

## Applicability

DDC systems may not be appropriate for very small schools with very simple HVAC systems. Their applicability increases with the size of the facility, the complexity of the HVAC system, and the size of the district.

## Applicable Codes

Title 24 requires a seven-day time clock with a manual override as a minimum level of automatic control over HVAC systems.

## Integrated Design Implications

Coordination between mechanical and electrical consultants is necessary for supplying power to a DDC system. If the system is to integrate control of lighting and other building systems, significantly greater coordination will be required. It may also be desirable to have the DDC system use the building (or district-wide, if available) LAN for communications between controllers and with users. These decisions must be made early in the design phase to allow for coordination throughout the design.

## Costs

\$0.50 to \$1.50 per ft$^2$. \$300 to \$500 per input or output "point". Special O&M training required to operate, maintain, and troubleshoot DDC systems. Periodic recalibration of sensors may required for precise control. Software upgrades periodically required and life expectancy of major system components may be as low as 8-10 years due to the rapid pace of development of computer technologies.

## Benefits

Energy savings may be realized from a DDC system that is correctly installed and actively maintained. Additionally, comfort conditions may be more easily and consistently attainable and improvements can be made in O&M resource utilization through the use of the DDC system for fine tuning, analysis and trouble shooting.

Peak electric demand savings are possible through load management controls. A DDC system can be programmed to shut off or reduce power to specific loads during times of high peak demand charges. The savings can be significant, especially if implemented throughout a district.

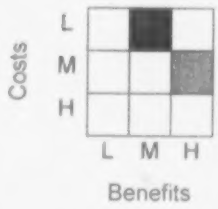
Comfort improvements and energy savings may be achieved through such features as adaptive optimum start programs that learn when to start morning warm up to achieve comfort at occupancy time for different operating conditions such as Monday mornings (when the building may have cooled off more than on other mornings.

DDC systems can also offer the benefit of remote monitoring of system status from a central office and help reduce time spent on maintenance and trouble calls.

DDC systems have the added benefit of eliminating the air compressors required for pneumatic control systems, together with associated maintenance costs, failures, etc.

## Cost Effectiveness

Cost effectiveness can be very high, with simple paybacks commonly estimated at 4 to 15 years. However, benefits will only be realized when certain conditions are met: The system must be programmed carefully, checked out thoroughly, and maintained actively. If O&M personnel are not comfortable with the system, it is likely to be bypassed, so good training is critical. Many school districts find that the greatest benefit of DDC systems is as a maintenance tool, allowing remote adjustment and troubleshooting of equipment.



## Design Tools

Control system manufacturers and their representatives are usually eager to assist with the design process (or take it over, if possible). This resource should be used with care not to overlook design engineer's responsibility to specify a well-engineered system. Close attention to development of the sequence of operation is always worthwhile. Software is available to chart sequences of operation in block diagrams or flow charts, commercially and from control manufacturers.

## Design Details

- Keep controls as simple as possible for a particular function. They will generally be operated (or bypassed) to the lowest level of understanding of any of the O&M personnel responsible for the HVAC system.
- Rooftop Units are often available with optional factory installed control modules that will interface with the DDC system as an independent "node" allowing a high level of monitoring and control.
- Discharge air temperature sensors are necessary for troubleshooting, even if not required for control.
- Specify temperature sensors with adjustable set point to give teachers control.
- Specify training. Since O&M personnel will "inherit" the system, and its performance will ultimately depend on them, involve them as much as possible in design decisions.
- Specify at least 1year warranty, including all programming changes.
- By specifying the configuration of specific data trend logs (not just the capability to collect them) and submittal of them for review & approval at system completion, some system commissioning may be accomplished by the design engineer and/or other owner's representatives.
- Specify all software necessary for efficient system operation by O&M personnel to be provided as part of the system installation.
- Local DDC contractors will usually be willing to provide design assistance or even a "complete" design package. Great care should be taken in such collaboration, for it is unlikely that thorough engineering will be applied to the design. The control system should be carefully specified by the design engineer, and details left up to the installing contractor only after careful consideration.
- Control algorithms that may be specified to increase energy efficiency include: Optimal start time calculation based on learned building behavior; Operation of central equipment based on zone demand, including supply temperature or pressure reset; Night purge ventilation to cool building interiors with cool night time air in hot climates; Heating and cooling system lockouts based on current or predicted outside air temperature; or heating and cooling lockout when windows or doors are opened for natural ventilation (using security system sensor switches).
- Automatic alternation of redundant and lead/lag equipment based on runtime should be accomplished by the DDC system, with provision for operator over ride.

## Operation and Maintenance Issues

Calibration of critical points is required annually or semi annually. Alternation of redundant or lead/lag equipment for even wear may be triggered automatically or manually. Operation and Maintenance requires special training, particularly in the case of software, therefore consistency with existing systems may be desirable. Access to make permanent software changes should be carefully limited. Periodic checkout is necessary.

## Commissioning

Careful commissioning is critical for success of DDC system installations, and proper control operation is necessary for proper equipment operation. Since DDC software may be somewhat esoteric, lack of commissioning may mean that this important aspect of the contractor's work may never be inspected and therefore may never be finished to the desired level. Therefore it is a very good idea to provide for some commissioning of the control system by an independent party or organization representing the owner's interests. Submittal and review of contractor's input and output point verification test documentation should be required. Field calibration of any temperature sensors that must be accurate for proper control is necessary (factory calibration is adequate only for non-critical sensors, such as room temperatures with adjustable set points). One minimal but effective commissioning method is to specify submittal of trend data logs showing system operation in specified modes, for review by the design engineer. User interfaces including graphics (when specified) should also be reviewed.

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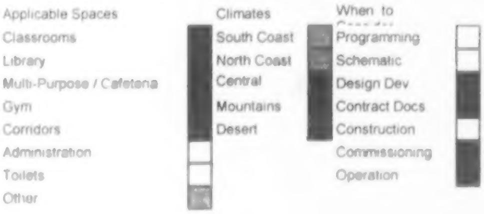
**Example(s)**

New Orchard School, San Jose, CA – Elementary.

# Guideline TC25: Demand Controlled Ventilation

CO2 Sensor

*(source: Honeywell)*



| Applicable Spaces | | Climates | | When to | |
|---|---|---|---|---|---|
| Classrooms | ■ | South Coast | ▨ | Programming | □ |
| Library | ■ | North Coast | ▨ | Schematic | □ |
| Multi-Purpose / Cafeteria | ■ | Central | ■ | Design Dev | ■ |
| Gym | ■ | Mountains | ■ | Contract Docs | ■ |
| Corridors | ■ | Desert | ■ | Construction | □ |
| Administration | □ | | | Commissioning | ■ |
| Toilets | □ | | | Operation | ■ |
| Other | ▨ | | | | |

## Recommendation

Specify controls to adjust ventilation rate for spaces with varying occupancy to prevent unnecessary cooling or heating of large quantities of outside air, and insure that adequate ventilation is provided when needed.

## Description

Many spaces in schools require high ventilation rates due to dense "design" occupancy, but experience this occupancy level sporadically or occasionally. The outdoor air required may represent a very large heating or cooling load depending on the season and climate. Therefore substantial amounts of energy and wear on equipment may be saved by reducing the amount of ventilation during those times the space is partly occupied or unoccupied but temperature needs to be maintained. This may be accomplished using occupancy sensors or air quality ($CO_2$ concentration) sensors to control the quantity of ventilation air. This may be done either in conjunction with a DDC system or by independent controls.

## Applicability

For VAV, VVT, multi-zone or small packaged unit zones, occupancy sensors may be applied but must be enabled / disabled to meet Title 24 pre-occupancy ventilation requirements. For larger intermittently occupied spaces such as multi-purpose rooms, auditoriums, cafeterias and gyms, the energy savings may justify the added first cost, maintenance cost and complexity of a $CO_2$ sensing system that modulates the outside air quantity down from the design level when interior air $CO_2$ levels indicate partial occupancy.

## Applicable Codes

Title 24 minimum ventilation rates, including baseline for area (0.15 cfm/ft$^2$). Title 24 establishes a "floor" for ventilation, regardless of $CO_2$ concentration, and specifically addresses demand-controlled ventilation.

## Costs

Each $CO_2$ sensor: $500 to $1,000

Installation, testing and adjustment: $500 to $1,500 per system

Annual calibration

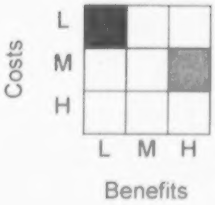
Hand held $CO_2$ sensor for calibration: $500.00

## Benefits

- Reduced energy consumption

- Reduced wear on equipment
- Confirmed / documented interior air quality

## Cost Effectiveness



Generally, cost effectiveness for occupancy sensor based control will be very high for larger systems. For $CO_2$ sensor based control, it will depend on the climate being "severe" enough, and the required ventilation rate being large enough so that the heating and cooling load reduction saves enough energy costs to offset the first cost of the $CO_2$ sensing equipment.

## Design Details

- Demand controlled ventilation responds to human occupancy only. Other sources of internal pollutants must be addressed with per-area baseline ventilation, targeted ventilation, etc. This should be considered very carefully before applying this type of control, especially to classrooms, where various odor sources may be used. Demand controlled ventilation always results in worse interior air quality than a properly adjusted system constantly delivering ventilation for rated occupancy.
- $CO_2$ sensor based ventilation control uses the measured $CO_2$ level as an indicator of the current occupancy level, so the ventilation rate may be adjusted accordingly. This is an important difference from using the $CO_2$ sensor as a direct indication of air quality.
- In areas where OA $CO_2$ concentration is relatively constant, ventilation may be controlled by a single return air sensor to maintain a fixed $CO_2$ limit. Otherwise, outdoor and return air sensors should be used.
- The setpoint must be calculated based on occupancy and activity level. For example, the $CO_2$ concentration for an office space designed at 15 cfm per person (sedentary adult) can be calculated at 700 ppm above ambient.

## Operation and Maintenance Issues

Calibration is required.

## Commissioning

Review system operation under varying occupancy. Correlate with balance report data for minimum and maximum OA damper positions. Verify acceptable levels of $CO_2$ concentration in space when occupied using hand held sensor. Perform all testing in non-economizer mode.

## References / Additional Information

ASHRAE Journal, April 1997. Interpretation of ventilation standard IC-62-1989-27.

ASHRAE Standard 62-99

## Guideline TC26: CO Sensors for Garage Exhaust Fans

### Recommendation

Use Carbon Monoxide (CO) sensors to prevent parking garage exhaust fans operating when they are not needed.

### Description

Parking garage ventilation is often provided by an exhaust fan operated during normal occupancy hours. However, the high ventilation rate required when traffic is present need not be maintained most of the time, when no vehicles are operating. Substantial energy savings may be realized by limiting fan operation to only those periods during normal occupancy when carbon monoxide concentration in the garage rises above acceptable levels. Carbon monoxide concentration sensor technology has advanced substantially in recent years, reducing cost and improving reliability.

| Applicable Spaces | |
|---|---|
| Classrooms | ☐ |
| Library | ☐ |
| Multi-Purpose / Cafeteria | ☐ |
| Gym | ☐ |
| Corridors | ☐ |
| Administration | ☐ |
| Toilets | ☐ |
| Other | ▨ |

| Climates | |
|---|---|
| South Coast | ■ |
| North Coast | ■ |
| Central | ■ |
| Mountains | ■ |
| Desert | ■ |

| When to Consider | |
|---|---|
| Programming | ☐ |
| Schematic | ☐ |
| Design Dev | ☐ |
| Contract Docs | ■ |
| Construction | ☐ |
| Commissioning | ■ |
| Operation | ■ |

### Applicability

School buildings with enclosed parking garages requiring mechanical ventilation.

### Applicable Codes

UMC

### Costs

$0.20 to $0.40 per square foot of garage. $1,000 – $2,000 per sensor installation.

### Benefits

Energy savings, wear reduction, noise reduction.

### Cost Effectiveness

Generally high, but depends on size of exhaust fan.

| Costs \ Benefits | L | M | H |
|---|---|---|---|
| L | ■ | | |
| M | | | ▨ |
| H | | | |

### Design Details

- Diesel exhaust does not contain high levels of CO. Consider $NO_2$ sensors if substantial traffic or idling of diesel vehicles is anticipated.
- Include time of day control in addition to CO concentration control.
- Sensor coverage area limited – multiple sensors may be required.
- Specify calibration tools provided to O&M personnel at time of training.

### Operation and Maintenance Issues

- Annual calibration of sensor(s) required

**Commissioning**

- Verify threshold adjustment and verify function.
- Verify training of O&M personnel including calibration.

**Example(s)**

Jean Parker Elementary School, San Francisco Unified School District, San Francisco, CA

# OTHER EQUIPMENT AND SYSTEMS

This chapter discusses systems that significantly improve the resource efficiency and performance of existing services, mechanisms and equipment. These systems also improve energy management by reducing energy use and peak loads. They work through using abundantly available solar radiation or conserving and recycling water. In particular, this chapter provides technical guidelines for the use of:

Photovoltaics (Guideline OS1)
Solar Heating for Pools (Guideline OS2)
Rainwater Collection Systems (Guideline OS3)
Gray Water Systems (Guideline OS4)
Timers for Recirculating Hot Water Systems (Guideline OS5)
Low-flow Terminal Devices (Guideline OS6)
Waterless Urinals (Guideline OS7)
Relocatable classrooms (Guideline OS8).

## Overview

The equipment and systems described in this chapter can all be used to emphasize that high performance schools are "buildings that teach." Some of these systems are highly visible, making them ideal teaching tools. A photovoltaic array on a school building, for example, lends itself more readily to teaching opportunities than a remote power station does. Teachers can show students how photovoltaics produce on-site electricity, and can encourage students to think about the energy source that powers the systems that keep them comfortable. Collecting and recycling rainwater establishes water as a precious resource not to be taken for granted. Such systems also require a higher level of involvement from the people who benefit from them, as their maintenance and functioning is the direct responsibility of the school staff.

Introducing these systems in schools promotes their acceptance on a broader community level. Although concerns about health and sanitation issues hold back widespread rainwater and gray water recycling, there are no studies that bear out these concerns. Often, becoming familiar with water recycling systems is the first step toward accepting them; schools are a good place for students, teachers, parents and the community to become acquainted with these systems. Waterless urinals face the same challenges. Some people who are not familiar with waterless urinals may be concerned about unpleasant odors or unhygienic conditions. But in fact the special liquid used in the traps for these urinals does not allow odors to escape the trap. And the no-touch system actually enhances hygiene and prevents overflow. Again, getting used to the system is the key to acceptance.

The main characteristics of the equipment and systems described here are that they utilize sustainable practices and require little or no fossil fuel-generated energy to operate. Photovoltaics and pool heaters, for example, use radiant and thermal energy from the sun. Rainwater systems recycle water from a source that replenishes itself, and help restore the water table. Gray water recycling, low-flow terminal devices, and waterless urinals conserve clean water and reduce the load on water treatment plants. Some of them may use electricity for pumping water, but this is reasonable trade-off compared to the thousands of gallons of clean water saved.

Due to the way energy cost is typically defined, many of these systems tend to have high payback periods. But what we pay for one kWh of electricity does not include many environmental costs, which may include adding greenhouse gases to the atmosphere, using fuels that are not abundantly available or not replenished, or damaging ecosystems. Similarly, what we pay for water does not take into account “hidden” environmental costs. Consequently, systems like rainwater and gray water recycling that save thousands of gallons of clean water, may save little in dollar terms. Only an environmentally balanced life-cycle cost assessment will ascertain the real payback period for these systems. Such systems may also have high first costs because they do not benefit from economies of scale of mass-produced systems. Because these systems are emerging technologies, they have not yet achieved critical manufacturing volume. But using these systems in high performance schools will make valuable contributions toward their gaining greater market share and acceptance.

# Guideline OS1: Photovoltaics

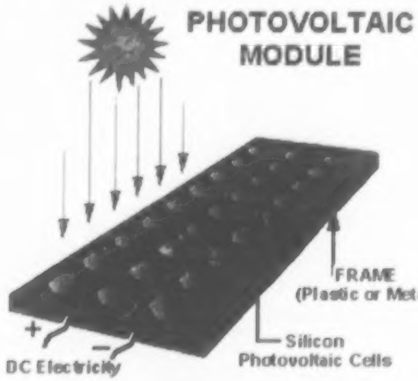
**Recommendation**

Install photovoltaics arrays to convert radiant energy from the sun to electricity. Photovoltaics are ideal for isolated or stand-alone tasks.

**Description**

Photovoltaics (PVs) convert radiant energy from the sun into direct current electricity. PVs convert solar energy into electrical energy without any environmental costs (greenhouse or acid gas emissions) associated with other methods of electricity generation.

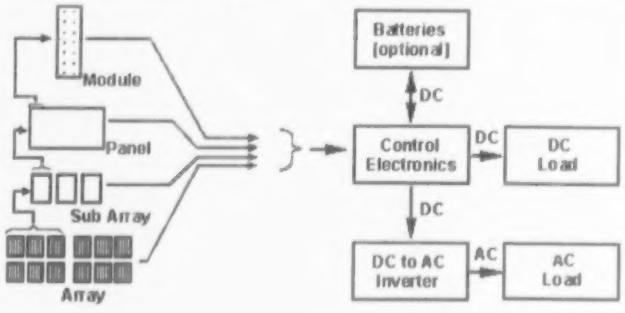
More solar energy strikes the earth than the worldwide energy demand each year. PVs produce electricity from an abundant, reliable, and clean source.



The basic component of a photovoltaic system is a solar cell. Most solar cells are made of specially treated silicon semiconductor materials. Sunlight striking the cells generates a flow of electrons. This flow is directly proportional to the surface area of the cells and the intensity of the radiation (a cell of area 6.25 in$^2$ will produce 3.5 amperes in bright sunlight). Each solar cell produces approximately 0.5 V. Higher voltages are obtained by connecting the solar cells in series. The typical photovoltaic module uses 36 silicon solar cells, connected in series to provide enough voltage to charge a 12-volt battery. Solar cells are laminated- most have a tempered glass cover and a soft plastic backing sheet. This sealing protects the lodged electrical circuits from the outside and makes solar cells durable. Modules may be connected in series for higher voltages and in parallel for higher currents.

source: http://www.nrel.gov/research/pv/docs/figure1.jpg

| Applicable Spaces | | Climates | | When to Consider | |
|---|---|---|---|---|---|
| Classrooms | ☐ | South Coast | ■ | Programming | ☐ |
| Library | ☐ | North Coast | ■ | Schematic | ☐ |
| Mulit-Purpose / Cafeteria | ☐ | Central | ■ | Design Dev | ▨ |
| Gym | ☐ | Mountains | ■ | Contract Docs | ☐ |
| Corridors, | ☐ | Desert | ■ | Construction | ■ |
| Administration | ☐ | | | Commissioning | ■ |
| Toilets | ☐ | | | Operation | ■ |
| Other | ☐ | | | | |



*PV System Diagram*

Individual modules may be further combined into panels, sub arrays, and arrays. Photovoltaic arrays with storage batteries are sources for uninterrupted power supply. Batteries are required to store energy collected during the day for nighttime use. A battery charger controller may be included to avoid overcharging the battery. In addition, all systems include wire, connectors, switches, and electrical protective components. If the load requires alternating current (ac), an inverter is used to convert the dc power to ac power. A simplified block diagram of a typical photovoltaic power system is shown below. Batteries are required in photovoltaic-powered lighting systems. The energy collected during the day is stored for use during the night.

### Applicability

- Photovoltaics are very suitable for remote facilities that are more than one-third of a mile away from the electrical grid.
- Photovoltaics are ideal for climates where plenty of sunlight is available. It's also suitable for climates that may experience cloudy days periodically but have sunlight available on most other days.
- PVs are ideal for providing power for exterior lighting and lighting for parking lots.

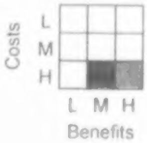
### Applicable Codes

The National Electric Code (NEC) applies to all systems that generate, store, transport, and consume electricity. Follow equipment requirements of NEC so that the PV system can be approved by local electric code officials. Be aware that many states require all electrical equipment to be installed by a licensed electrician.

### Integrated Design Implications

- Building aesthetics- PVs should be mounted on roof tops for best results and this needs consideration in the early design stage.
- System integration- PVs are most likely to be used in hybrid systems. This will require detailing and planning by the mechanical engineer in the early design stages.

### Costs



Photovoltaic panels typically cost anywhere between $3.5-$5/W for modules and $5-$20/W for the system depending on the size and capacity of the installation (each watt of PV array will produce 2-6 watts-hours of energy depending on availability of sunlight). 100 W installations will cost between $10-$12/W. Using typical borrowing costs and equipment life, the life cycle cost of PV generated energy generally ranges from $0.25 to $1.00/Kwh. The simple payback period for this system is 20-30 years.

### Benefits

- Photovoltaics are most cost effective in remote locations that are at a distance from an electrical grid. PVs are typically 3-6 times more expensive than utility-supplied electricity (this does not however, take into account the 'real' or environmental cost of utility generated electricity).

- Photovoltaics are environmentally benign and do not produce any greenhouse gases or acid gas emissions associated with other methods of generating electricity. They have zero environmental costs.
- PVs produce electricity from an abundant and reliable source or 'fuel'- sunlight. Coupled with storage batteries they are capable of supplying uninterrupted power.
- PVs are available in modular building blocks- more arrays may be added as the demand for power increases.
- They have no moving parts and produce power silently- minimizing wear and tear.
- They require no connection to an existing power source or fuel supply, although they may be combined with other power sources to increase system reliability (hybrid systems).
- They can withstand severe weather conditions including snow and ice.
- PVs can be combined with other types of electric generators (wind, hydro, and diesel, for example) to charge batteries and provide power on demand.
- PVs can also put power back into the electrical grid and shave peak loads. This can have far-reaching implications.

### Design Tools

If you need or want a customized system, most photovoltaic dealers will work with you to engineer the best system for your application. They will help you determine your requirements by:

- Estimating the daily load demand
- Determining the solar resource in your area
- Calculating the battery size
- Calculating the number of photovoltaic modules required

For your own first estimates of the array size you will need, consider the following variables that effect the production of power in an array:

- outside air temperature (use average annual temperatures)
- amount of sunlight received (Incident Solar Radiation- this depends on latitude, cloud cover, and angle of the array)
- efficiency of the photovoltaic cells (this should be available from the manufacturer and varies between 13% at unfavorable conditions to 30% under lab conditions)

$P = (Sol_{ins} + \Delta t) \times A \times Eff$

where,

$P$ =Power generated, W

$Sol_{ins}$ = Incident solar radiation, $Wh/ft^2$

$\Delta t$ =Difference between the control and design temperatures (use 0 if the design temperature is between 50°F and 60°F, for control temperature use 50°F for colder weather and 60°F for warm weather)

$A$ =Area of the array, $ft^2$

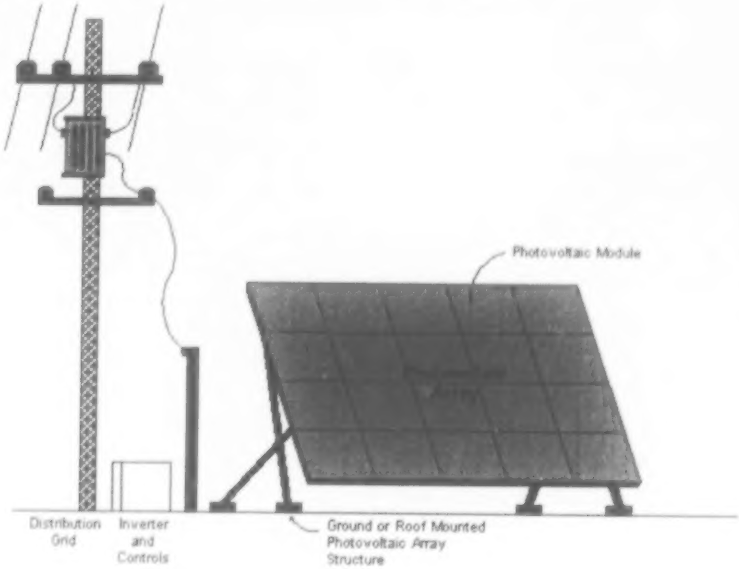
$Eff$ =Efficiency of the system (multiply cell efficiency by efficiency of the storage unit)

A Macintosh software is available for PV design and sizing, wherein designers can specify appliances and AC/DC loads, inverter efficiency, and site location. Based on these variables, the software recommends number of solar modules and batteries. Cost: $15.

Another software, Solar Pathfinder, quickly evaluates solar potential and gives recorded solar site information for the entire year. It shows energy lost due to each shadow casting object and a fast comparison to other sites. Since shading just one cell in a PV module reduces output by up to 80%, a Pathfinder can more than pay for itself.

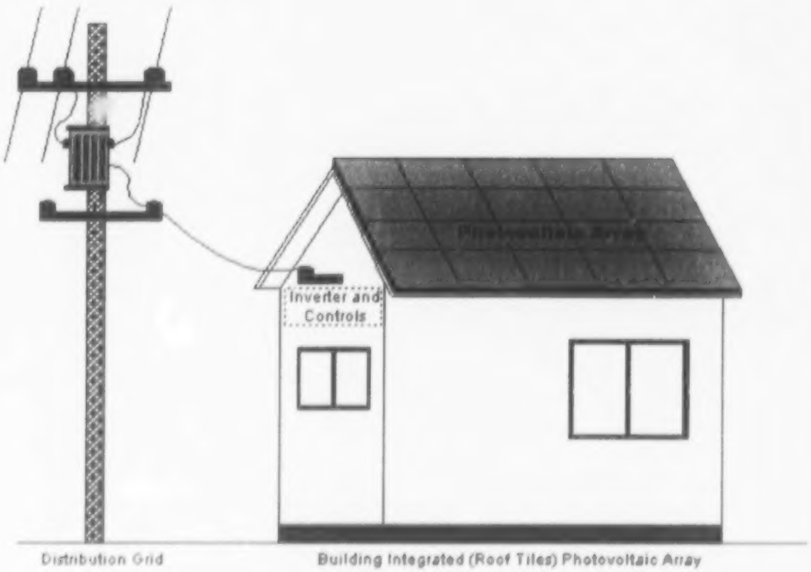
Trnsys, a program developed at the University of Wisconsin also helps size and locate PVs. For more information contact: Solar Engineering Laboratory, University of Wisconsin-Madison,1500 Engineering Drive, Madison, WI 53706, Phone: (608) 263-1589; Fax: (608) 262-8464, Email: trnsys@sel.me.wisc.edu, World Wide Web: http://sel.me.wisc.edu/trnsys

### Design Details



*Source: Renewable Energy Project Analysis Software*

- The most important aspect of installing PVs is its siting. Shading can significantly reduce the output of solar cells. Mount PVs at an elevation or on roof tops. Consider both summer and winter sun paths and ensure that trees, neighboring buildings, or other obstructions do not shade any portion of the array between 10:00 a.m. and 3:00 p.m.
- Mount PVs for maximum southern exposure. The exact mounting angle will differ from site to site.
- Flat, grassy sites work better than steep, rocky sites.



*Source: Renewable Energy Project Analysis Software*

- Use arrays as building components to economize to building materials and for unobtrusive design solutions. Arrays can be used as a finishing material on structures to create attractive roofs or skylights. Arrays can be used to break up and add interest to a large surface that might have been one roofing material. They can double as shading devices, which not only block the sun but also capture it. Transparent arrays can be used as structural glazing instead of glass. Arrays can be used as part of a curtain wall system.

### Operation and Maintenance Issues

- PVs require occasional cleaning- in cold climates where it snows care must be taken to keep the array surface clear of snow.
- Most PV systems contain storage batteries that may require some watering and maintenance similar to that required by batteries in automobiles.
- PV modules are the longest living components of a PV system (20-30 years) and likely to outlive the batteries (7 years). Batteries may need replacement every 6 or 7 years.
- No PV system is maintenance-free. Schedule regular inspections of your system to ensure that the wiring and contacts are free from corrosion, the modules are clear of debris, and the mounting equipment has tight fasteners.
- Monitor the power output of PV modules, the state-of-charge and electrolyte level of your batteries, and the actual amount of power that building loads use. Writing this information in a notebook is a good way to track the system's performance and help determine whether the system is operating as designed. Monitoring will also help understand the relationships between the system's power production, storage capability, and load requirements.

### Commissioning

- Do not compromise on the initial module cost of PV systems. You may have to pay later in terms of higher operation ($/kWh) costs that will amount to a much higher figure over the lifespan of a system.

- Purchase PV systems from established and knowledgeable dealers who can help you with requirements specific to your site. Look for 20+ years warranties. Thoroughly check the rating system that the dealer/manufacturer is using for reliability.
- Always engage a professional to design and install PV systems. A preliminary design is a necessity in order to determine the size, layout, and potential energy output of the PV modules. This can be performed with computer simulation tools using estimated hourly weather, solar resource, and load data. The time required to prepare the preliminary design and detailed cost estimate typically falls between 30 and 60 hours at fees between $40/h to $100/h. Smaller scale projects with simple structural requirements are at the low end of this time range. Larger scale projects requiring more difficult structural integration into existing buildings will be at the high end of this time range.

### Example(s)

For Maryland Solar Schools Program Plan see http://www.energy.state.md.us/executiv.htm

### References / Additional Information

Stand-Alone Photovoltaic Systems: Handbook of Recommended Design Practices, Sandia National Laboratory

Energy Efficiency and Renewable Energy Network (EREN), US Department of Energy

# Guideline OS2: Solar Pool Heating

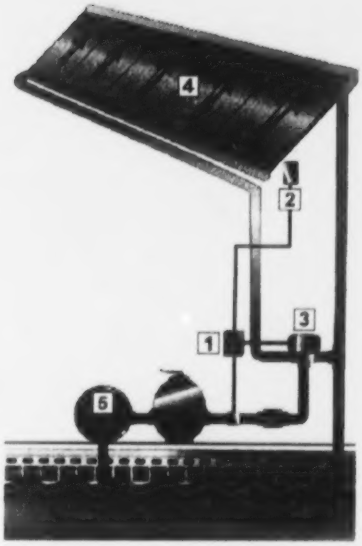
## Recommendation

Use solar heaters for swimming pools for an environmentally friendly and cost effective solution to pool heating requirements.

## Description

Most solar pool heating systems consist of three basic components: a collector, a pump, and a controller. Unlike solar domestic water heating systems, which raise a small amount of water to a high temperature of about 140°F, pool heaters raise the temperature of several thousand gallons of water to about 80°F by circulating the water at a relatively fast rate through the collectors. This allows most of the solar energy falling on the collectors to transfer to the pool water.

The collector consists of a large area of pipes that absorb solar energy in the form of heat. They are made from plastic or rubber compounds that can withstand continuous exposure to sunlight. The collector is positioned for maximum access to sunlight. The pump circulates water through the collector where it continually absorbs heat. The hot water is then pumped back to the pool. This pump may be separate (especially in retrofit situations) from the regular pool pump that circulates pool water through a filter. The pump is automatically switched off when the temperatures of the water in the pool and the collector approach each other. The controller regulates the flow of water within the collector based on the temperature of the outgoing water. This contains the only moving part in a solar pool heating system- the diverting valve. This valve controls whether or not the water circulates through the collector loop. When the collector temperature is sufficiently greater than the pool temperature, the water is diverted from the filter systems through the collector loop. The water bypasses the solar collectors during nighttime or cloudy periods. Some smaller systems are operated manually or with timers but larger systems may be operated through electronic sensors.



*Source: Solar-Tec Systems Solar Pool Heating*

*With a Solar-Tec Systems Pool Heating System you have a choice of two control systems. A manual control where you turn the system on or off by turning the handle on a three-port control valve, or a fully automatic electronic control system. With the automatic system you simply set the desired temperature on your control panel (1) and the system does the rest. When the solar sensor (2) finds that there is enough solar energy to heat your pool and your pool is colder than you desire, water is automatically sent to your solar collectors (4) by the valve (3). Bright sunshine is not needed to heat your pool. The solar sensor will turn on your solar system even on a hazy or cloudy day when it finds the right amount of solar energy. Your pool pump (5) sends pool water to the solar collectors. As the water flows through the many tubes in each solar collector the sun's energy heats it. The solar-heated water then flows back to your pool. This simple cycle continues until your pool reaches your desired temperature. You can cool an overheated pool in warmer months by simply running the pool pump at night. Your control system will automatically switch to cooling your pool.*

Strip, panel, and tube systems are three major types of solar collectors available. All three types of collectors perform to a more or less equal standard although strip systems are the most commonly used type.

## Applicability

Solar heating for swimming pools is feasible for all climate types- even those that experience sub-freezing temperatures. Waterways on strip systems can expand to accommodate the increased volume of frozen water.

Most sloping roofs can be fitted with solar collectors. Strip systems, that are relatively lightweight, are suitable for sloping roofs. Strip collectors can be fitted to follow the roof contours and can be curved around obstructions such as chimneys and skylights. Panel collectors are limited by their rigid sheet design and can be applied to flat or plane roofs only.

| **Applicable Spaces** | |
|---|---|
| Classrooms | ☐ |
| Library | ☐ |
| Mulit-Purpose / Cafeteria | ☐ |
| Gym | ☐ |
| Corridors | ☐ |
| Administration | ☐ |
| Toilets | ☐ |
| Other | ☐ |

| **Climates** | |
|---|---|
| South Coast | ■ |
| North Coast | ■ |
| Central Valley | ■ |
| Mountains | ■ |
| Desert | ■ |

| **When to** | |
|---|---|
| Programming | ☐ |
| Schematic | ☐ |
| Design Dev | ▨ |
| Contract Docs | ☐ |
| Construction | ■ |
| Commissioning | ■ |
| Operation | ▨ |

## Applicable Codes

Title 24 allows for exceptions to Section 114 (a) 4 (that prohibits electric resistance heating) and Section 114 (b) 2 (that requires pool covers) for pools deriving at least 60% of the annual heating energy from site solar energy. Other codes may apply.

## Integrated Design Implications

Although solar heated swimming pools can easily be accommodated later in the design or construction phases, the following issues should be considered beforehand:

- Building Aesthetics. Installation of solar collectors on rooftops may conflict with building aesthetics. Consider placement and orientation of the collectors early in the design phase to avoid this conflict.
- Space availability. Solar collectors may occupy an area equivalent to up to 75% of the surface area of the pool they serve. This roof area must be available near the location of the swimming pool for unobstructed access to sunlight (although it's possible to mount the collectors at ground level).

## Costs

Collectors made of copper are more expensive than those made of plastic, although they last longer. Plastic ones are less conductive than copper but are inert to chemicals and have about a 10-year lifespan. On an average, solar heating systems for pools cost around \$7.5/ft$^2$-\$10/ft$^2$ (installed). An unglazed solar heating system for an average 600 ft$^2$ pool, including separate pump and automatic controller, costs around \$4500 fully installed. The operating energy is practically free, as all the heating energy is solar.

| Costs | L | M | H |
|---|---|---|---|
| L | ☐ | ■ | ☐ |
| M | ☐ | ☐ | ☐ |
| H | ☐ | ☐ | ☐ |

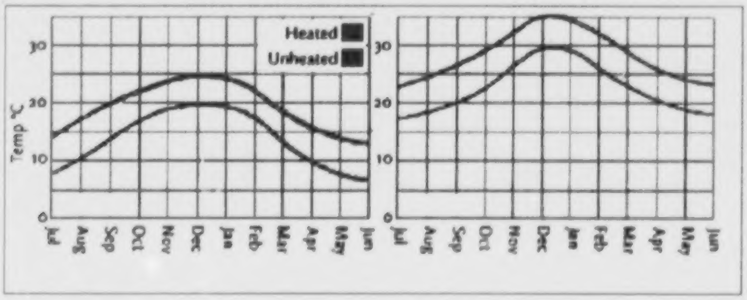
Benefits

Pool covers for average size (600ft$^2$) pool costs around \$400 to \$500 (not including the roller, which has a starting cost of around \$300). Using the above figures for the cost of running a gas heater, heating your pool with solar energy can save from 3.8 to 5.1 tons of greenhouse gas emissions ($CO_2$) per year.

## Benefits

- Solar pool heating collectors operate just slightly above the ambient air temperature (80°F). Therefore, such systems typically use inexpensive, unglazed, low temperature collectors made from especially formulated plastic materials.
- The alternative- a gas pool heater- has a starting price of around \$2000, plus additional heating costs varying between \$600-\$900 per year. The solar system will therefore repay the extra cost in less than 3-4 years and will have much lower running costs thereafter.
- A solar system requires very little or no maintenance since there are no burners and no moving parts. A gas heater or heat pump requires far more maintenance and typically lasts only one-third the life span of a solar system.

- Solar systems' warranties are typically more inclusive and much longer (12-15 years) than warranties for gas heaters (5 years) and heat pumps (typically 10 years).
- A good solar pool heating system can generally be expected to increase pool water temperature by 9°F-18°F above the unheated water temperature from October to March. However, this will vary depending on local climate conditions. The graphs below show the temperature differences claimed by one manufacturer in two climate extremes.



- Attic insulation gets saturated with radiant heat from roof decks that increasing air conditioning bills. Collectors mounted on the roof will considerably lower air conditioning cost for that space.

*Table 1 -- Cost comparison for gas and solar pool heaters in a heating dominated climate*

| Gas Pool Heater | Solar Pool Heater |
|---|---|
| Initial cost $2,400 | Initial Cost $3,495 |
| 5 year operating cost $6,000 | 5 year operating cost $0 |
| Total 5 year cost $8,400 | Total 5 year cost $3,495 |

## Design Tools

Use the following simplified algorithm for arriving at the required collector area:

$A = A_p \times O \times S \times Sol_{ins}$

Where,

$A$ =Area of solar collector, $ft^2$

$A_p$ =Effective area of pool (multiply the surface area of the pool with the shape multiplier from Table 2), $ft^2$

$O$ =Orientation multiplier (from Table 3)

$S$ =Shading multiplier (from Table 4)

$Sol_{ins}$ = Solar insulation (from figure below)

*Table 2 – Shape multiplier*

| Shape | Multiplier |
|---|---|
| Rectangle | 1.00 |
| Kidney/Freeform | 0.85 |
| Oval | 0.90 |
| Round | 0.79 |

*Table 3 – Orientation multiplier*

| Orientation | Multiplier |
|---|---|
| South facing | 1.00 |
| East or West facing | 1.25 |
| Flat | 1.10 |

*Table 4 – Shading multiplier*

| Shading (from 9 a.m. to 5 p.m.) | Multiplier |
|---|---|
| No Shade | 1.00 |
| 25% shade | 1.10 |
| 50% shade | 1.25 |
| 75% shade | 1.50 |
| 100% shade | 1.75 |

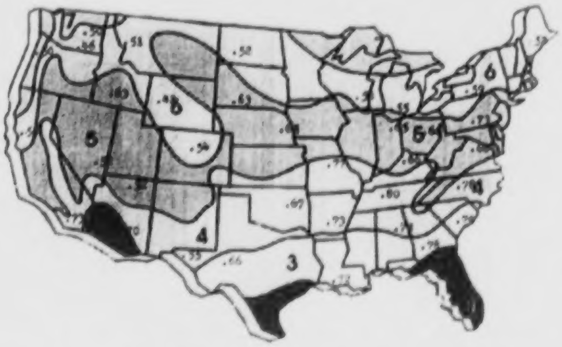


*Figure 21 – Solar Insulation Levels in the US*

Free software to analyze current energy consumption and project savings when implementing a variety of energy management systems from pool covers to solar systems is available from US Department of Energy. The *Energy Smart Pools* software uses hourly temperature and humidity data along with solar data to provide an accurate simulation of the heat losses and gains of a pool. Over 50 U.S. weather sites are currently available in the software. The program is intended to provide annualized simulation of annual energy costs, other costs, savings, and payback of adding a pool cover system; costs, savings, and payback of adding a solar heating system.

### Design Details

As in all solar heating, the primary factor in determining the effectiveness of the system is exposure to the sun. The size and the location of the collector, controller efficiency, local climate, wind protection, and roof orientation- all influence the functioning of solar pool heating systems.

- Use a minimum collector area of 60% of the surface area of the pool. This applies only for ideal conditions (see design tools for simplified sizing). Whenever conditions are unfavorable, for example in colder climates, the size of the collector will need to be increased. A minimum area of 80% is recommended for such installations. Increase collector area to 75% if collectors are laid flat or if collectors face west. Other orientations are not recommended. In general, for every 20% of the pool surface area that is installed as solar collector, a 3°F rise in water temperature can be expected (based on collector rating at 1,000 BTU/ft$^2$ of collector area).
- A south facing roof is the best location. Use a west orientation or a flat roof if south orientation is unavailable.
- Ideally, tilt the south facing collectors by 30-32°.
- Consider installing pool covers – they are the most cost effective measure for reduce heat loss, water evaporation, and chemical use.
- Manual operation, or a simple timer maybe substituted for expensive automatic controls.

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- Indoor pools that are used year round require glazed flat plate collectors, which should slope between 35 and 45 degrees.

### Operation and Maintenance Issues

- Ensure that pools are manually and seasonally drained. In areas subject to winter freezing, the collectors and plumbing should be installed to allow all water to drain when the system is off.
- Paint all exposed PVC plumbing, to protect it from damage due to solar energy.

### Commissioning

Carefully check how long the manufacturer has been in business and what warranty services are available. Use the Florida Solar Energy Center rating system.

### Example(s)

### References / Additional Information

American Solar Energy Society, Inc. (ASES) , 2400 Central Avenue, G-1 , Boulder, CO 80301 , Phone: (303) 443-3130; Fax: (303) 443-3212 , Email: ases@ases.org , Web site: http://www.ases.org/

National Spa & Pool Institute (NSPI), 1-800-323-3996, Web site: http://www.nspi.org/

The Energy Efficiency and Renewable Energy Clearinghouse (EREC), P.O. Box 3048, Merrifield, VA 22116, 1-800-DOE-EREC (1-800-363-3732), E-mail: doe.erec@nciinc.com , Web site: http://www.eren.doe.gov/consumerinfo/

Florida Solar Energy Center , 1679 Clearlake Rd. Cocoa Florida 32922, 407/638-1000 fax: 407/638-1010, Pamphlets available by mail - call for costs, Collector Thermal Performance Ratings (publication FSEC-GP-16), Design and Installation Manual (publication FSEC-IN-21-82), System Sizing (publication FSEC GP-13)

Solar Energy Industries Association (SEIA), 1616 H Street, NW, 8th Floor, Washington, DC 20006, Phone: (202) 628-7979, Fax: (202) 628-7779, Web site: http://www.seia.org

Alternative Energy Systems Co. of Mississippi, 22 Dillard Road, Poplarville MS 39470, email info@aesms.com or phone 601-772-9966 , www.aesms.com

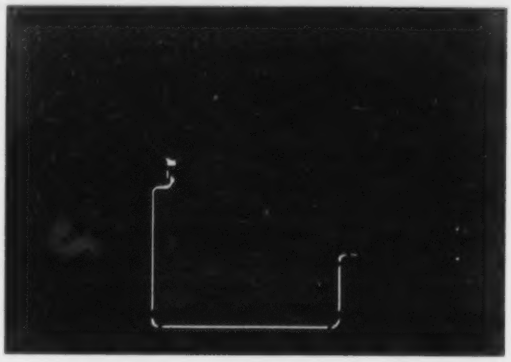
# Guideline OS3: Rainwater Collection Systems

## Recommendation

Use rainwater-harvesting systems for supplying year-round, dependable potable or non-potable water.

## Description

Drawing excessive water and paving up all available open land have considerably hindered natural ground water recharge. Rainwater harvesting is merely 'putting back rain water into the soil'. Rainwater is collected from roof or ground level surfaces and stored in a cistern. The water is then filtered and delivered to terminals through pumps. Rainwater is used for showers, sinks, laundries, dishwashers, in flushes, and sparingly- even for drinking. The components of a rain water system include:



*Schematic of a rainwater collection system*

| Applicable Spaces | | Climates | | When to Consider | |
|---|---|---|---|---|---|
| Classrooms | ☐ | South Coast | ■ | Programming | ☐ |
| Library | ☐ | North Coast | ■ | Schematic | ■ |
| Multi-Purpose / Cafeteria | ☐ | Central | ■ | Design Dev | ■ |
| Gym | ☐ | Mountains | ■ | Contract Docs | ☐ |
| Corridors | ☐ | Desert | ■ | Construction | ■ |
| Administration | ☐ | | | Commissioning | ▨ |
| Toilets | ☐ | | | Operation | ▨ |
| Other | ☐ | | | | |

- Catchment area/roof is the surface upon which the rain falls. Roofs are most commonly used as catchment areas although channeled gullies or other ground level features can serve the purpose equally well.
- Gutters and downspouts are the transport channels from catchment surface to storage. Water collected by the catchment area is delivered to the storage tank (or cistern) via gutters and downspouts. These need to be appropriately sized and sloped. Standard designs for these 'transport systems' are readily available in the market.
- Leaf screens and roof washers remove contaminants and debris.
- Cisterns or storage Tanks store the collected rainwater. Cisterns are the most expensive component of the rain water system.
- Conveying or delivery system for the treated rainwater is accomplished by means of pumps or gravity. The water pressure for a gravity system depends on the difference in elevation between the storage tank and the faucet. Water gains one pound per square inch of pressure for every 2.31 feet of rise or lift. Many plumbing fixtures and appliances require 20 psi for proper operation, while standard municipal water supply pressures are typically in the 40 psi to 60 psi range. To achieve comparable pressure, a cistern would have to be 92.4 feet (2.31 feet X 40 psi = 92.4 feet) above the highest plumbing fixture of the facility. This means pumps are essential to convey the filtered water from cisterns to terminal devices.
- Water treatment, filters and equipment, and additives to settle, filter, and disinfect the collected water are important components of this system. It is essential that a professional decide the water treatment method to use for a given facility after conducting appropriate water tests in a laboratory. This will determine whether this water will be applicable to potable or non-potable uses. Types of treatment include filtration, disinfection, and buffering for pH control. Dirt, rust, scale, silt and other suspended particles, bird and rodent feces, airborne bacteria and cysts will inadvertently find their way into the cistern or storage tank even when design features such as roof washers, screens, and tight-fitting lids are properly installed. Water can be unsatisfactory without being unsafe; therefore, filtration and some form of disinfection is the minimum recommended treatment if the water is to be used for human consumption.

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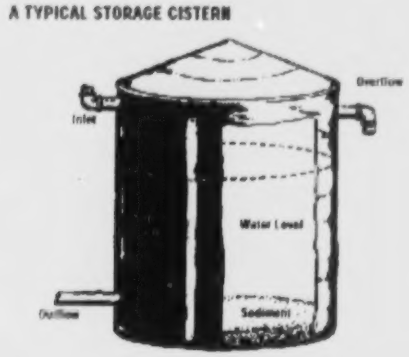


*Figure 22 – Cistern for rainwater collection*

*Source: Texas Rainwater Guide*

The catchment area is the surface on which the rain that will be collected falls. While this Guide focuses on roofs as catchment areas, channeled gullies along driveways or swales in yards can also serve as catchment areas, collecting and then directing the rain to a French drain or bermed detention area. Because composite asphalt, asbestos, chemically treated wood shingles and some painted roofs could leach toxic materials into the rainwater as it touches the roof surface, they are recommended only for non-potable water uses.

Gutters and downspouts are the components that catch the rain from the roof catchment surface and transport it to the cistern. Standard shapes and sizes are easily obtained and maintained, although custom fabricated profiles are also available to maximize the total amount of harvested rainfall. Gutters and downspouts must be properly sized, sloped, and installed in order to maximize the quantity of harvested rain.

Other than the roof, which is an assumed cost in most building projects, the storage tank represents the largest investment in a rainwater harvesting system. To maximize the efficiency of your system, your building plan should reflect decisions about optimal placement, capacity, and material selection for the cistern.

### Applicability

Rainwater systems are appropriate for most climates. In dry climates too, enough rainwater is available to meet 75% of the total water requirement of a facility.

Rainwater harvesting should be considered early in the design phase for best (and safe) results.

### Applicable Codes

State Department of Health codes will apply to potable water. The Texas Rainwater Guide recommends that the following practices be observed (although regulations will vary locally):

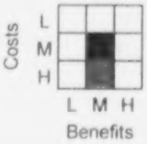
- A cistern should not be located closer than 50 feet from a source of contamination, such as a septic tank.
- A rainwater system must include installation of an overflow pipe that empties into a non-flooding area.
- An aboveground roof washer or filtering device shall be provided on all cisterns.
- The water intake for a pump in a cistern shall be attached to a flotation device and be located a minimum of 4 inches below the surface of the water.
- Overflow from rainwater systems cannot flow into wastewater systems.
- Cisterns shall be accessible for cleaning.

- All openings into the cistern shall be screened.
- Cisterns cannot be relied upon to provide potable water without adequate treatment consisting of roofwashing and continuous disinfection.

### Integrated Design Implications

- Site Planning. This is an important consideration in designing rainwater systems. Decisions regarding siting the cistern, creating natural slopes or gullies for channeling rainwater, and creating a pressure difference between the gutter spout and the cistern inlet should be made at the site planning stage.
- Building Aesthetics. Building aesthetics will be impacted depending on the choice of rainwater collecting element.

### Costs



A rainwater harvesting system designed as an integrated component of a new construction project is generally more cost-effective than retrofitting a system onto an existing building. This is because many of the shared costs (roof and gutters) can be designed to optimize system performance, and the investment can be amortized over time.

Generally rainwater systems cost about $1.00-$1.5 per gallon of collection capacity although factors like design, topography, and climate can significantly alter these numbers.

City supplied water is relatively inexpensive, although it must be added that municipal water cost is a simple number and does not include hidden environmental costs. Consequently, the pay back period for a full-service rainwater harvesting system where city water is available is rarely less than 30 years and can be as high as 90 years, assuming about present values for municipal water and approximate construction costs of $1.00 per gallon of collection capacity for a rainwater harvesting system.

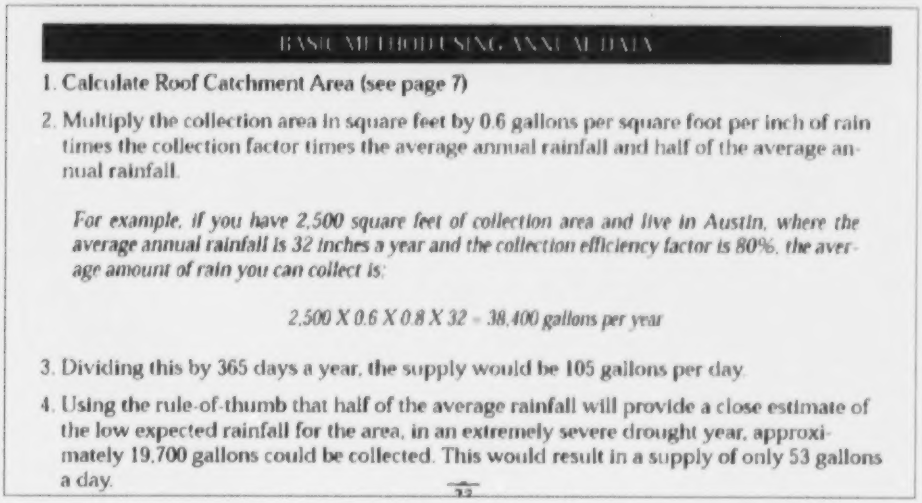
### Benefits

- It is an environmentally benign system.
- Rainwater quality is excellent.
- The concept is simple and easy to build. Operation and maintenance of systems are easy.

### Design Tools

For sizing catchment areas, it is reasonable to assume that 600 gallons is collected per inch of rain per 1,000 square feet:

$$\text{Catchment Area (ft}^2\text{)} = \frac{\text{Average Rainfall (inches)} \times 600}{1{,}000}$$



**BASIC METHOD USING ANNUAL DATA**

1. Calculate Roof Catchment Area (see page 7)
2. Multiply the collection area in square feet by 0.6 gallons per square foot per inch of rain times the collection factor times the average annual rainfall and half of the average annual rainfall.

   *For example, if you have 2,500 square feet of collection area and live in Austin, where the average annual rainfall is 32 inches a year and the collection efficiency factor is 80%, the average amount of rain you can collect is:*

   *2,500 X 0.6 X 0.8 X 32 = 38,400 gallons per year*

3. Dividing this by 365 days a year, the supply would be 105 gallons per day.
4. Using the rule-of-thumb that half of the average rainfall will provide a close estimate of the low expected rainfall for the area, in an extremely severe drought year, approximately 19,700 gallons could be collected. This would result in a supply of only 53 gallons a day.

*Source: Texas Rainwater Guide*

A number of computer software are available for sizing purposes. Rainwater System Simulator (RainSim) is a spreadsheet program developed by Rain Harvest, Inc. (now Sustainable Homesteads), that simulates the performance of a rainwater collection system. For every month of the simulation, it subtracts the water that is used and adds in any rainwater that was collected. The amount of water remaining in the cistern at the end of the month is output to a graph. A total of 100 years' rainfall data may be added to the program. The following values are manipulated for simulation:

- Size of the collection area in square feet
- Number of gallons that will be used each month
- Total size of storage capacity in gallons
- Amount of water in storage at the beginning of the simulation, in gallons
- Amount, if any, of water that will be put into storage if it is empty

A companion program, RainCalc, calculates waste production and peak flow rate based on the collection area and peak design rainfall rates to be expected in this area once every 10 years. RainCalc is used to properly design the collection plumbing system to catch all rainfall flowing off the roof without losing any to system backup.

## Design Details

- Collection area should be completely exposed and should not be shaded by trees. Rainwater yield and quality depends on the size and nature of the catchment area. Use smooth, impervious, and clean roofing for good quality yield. Textured roofing slows down water flow and is responsible for evaporative losses.
- Use pitched metal roofs to minimize losses. Metal roofs are also safe for potable water. Concrete or asphalt roof increase losses to 10%. Further loss in volume could occur if built up tar and gravel roofs are used. Clay and slate are also appropriate roofing choices for collecting potable water. Avoid roofing materials like asphalt, chemically treated wood, or asbestos for collecting potable water as they may introduce toxic matter in the rainwater.
- Surfaces like clay and slate should be treated with a special painted coating to discourage bacterial growth.
- Use aluminum or galvanized iron gutters and downspouts.

- Existing buildings should be fully examined for any lead content in the planning stages of any rainwater collection project.
- Locate cisterns below ground to benefit from cooler year-round ground temperatures. However, this may involve extra excavation and maintenance costs. Above ground cisterns also work well and may be installed if excavation costs are a major issue. Also placing the cistern at the highest workable level will reduce pumping costs.
- Use durable cisterns (ferrocement or wood work well) with watertight exteriors. All joints should be sealed with a non-toxic joint sealant. The tank needs to be Food and Drug Administration (FDA) approved if the water is intended for potable use. Use tight fitting covers to avoid losses due to evaporation and entry of pollutants into the tanks.
- To maximize efficiency and minimize piping costs, locate cisterns close to both the rainwater collectors and the demand terminals.
- It is a good practice to shield cisterns from direct sunlight- this prevents algae growth in the stored water.
- Site cisterns at least 50' away from sources of pollution like septic tanks.
- Cisterns should have vehicular access if the need to replenish the water through an auxiliary source arises.
- A settling compartment, which encourages any roof run-off sediment that may enter the tank to settle rather than be suspended in the tank, is an option that can be designed into the bottom of the cistern.

**CISTERN TYPES**

| MATERIAL | FEATURE | CAUTION |
|---|---|---|
| **PLASTICS** | | |
| Garbage Cans (20-50 gallon) | commercially available, inexpensive | use only new cans |
| Fiberglass | commercially available, alterable and moveable | degradable, requires interior coating |
| Polyethylene/Polypropylene | commercially available, alterable and moveable | degradable, requires exterior coating |
| **METALS** | | |
| Steel Drums (55 gallon) | commercially available, alterable and moveable | verify prior use for toxics, corrodes and rusts, small capacity |
| Galvanized Steel Tanks | commercially available, alterable and moveable | possible corrosion and rust |
| **CONCRETE AND MASONRY** | | |
| Ferrocement | durable, immoveable | potential to crack and fail |
| Stone, Concrete Block | durable, immoveable | difficult to maintain |
| Monolithic/Poured in Place | durable, immoveable | potential to crack |
| **WOOD** | | |
| Redwood, Douglas Fir, Cypress | attractive, durable | expensive |

*Source Texas Rainwater Guide*

## Operation and Maintenance Issues

- All tanks intended for storing potable water should be continually shaded from sunlight.
- Tanks should be regularly inspected and cleaned.
- The roof terrace (or rainwater collection system) should be regularly and thoroughly cleaned. Filters attached to rainwater conveying systems should be frequently cleaned to ensure maximum yield.

- Water from the first rains of the season should not be collected as it may contain atmospheric impurities and pollutants.

**Commissioning**

Buy durable cisterns with good warranties.

**Example(s)**

**References / Additional Information**

Center for Maximum Potential Building Systems, 8604 F.M. 969, Austin, Texas 78724. (512) 928-4786.

American Rainwater Catchment Systems Association, P.O.Box 685283, Austin, TX 78768-5283

American Water Works Association, 6666 West Quincy Avenue, Denver, CO, 80235

Water Quality Association, 4151 Naperville Road, Lisle, IL 60532

http://www.greenbuilder.com/sourcebook/Rainwater.html

http://www.waterwiser.org/

http://www.webcom.com/h2o/

# Guideline OS4: Gray Water Systems

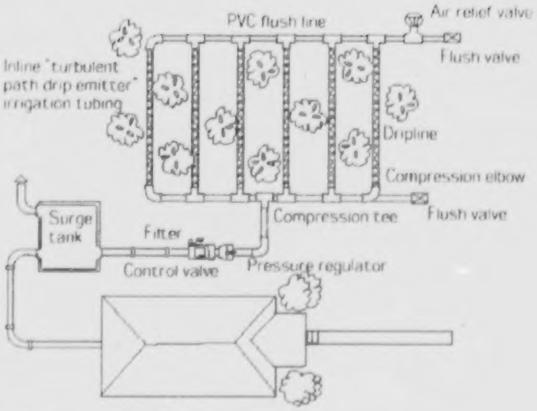
### Recommendation

Use gray water systems for drought-resistant landscape irrigation and for flushing toilets.

### Description

Gray water is untreated 'used' water that is not contaminated by toilet waste. The California Gray Water Standards define it to include used water from showers, bathroom washbasins, and water from washing machines. It does not include wastewater from dishwashers, kitchen sinks, or laundry water from soiled diapers. Gray water systems filter, sterilize, deodorize, and recycle this used water to be used for irrigating landscapes or flushing toilets.

Gray water systems have three major components: the drain-line plumbing, the surge tank and other equipments associated with it, and the delivery system. Surge tanks allow quicker inflow of water from the source than outflow to drainfields. A schematic from Appendix J of the California Plumbing Code identifies the components of a gray water system where gray water is delivered to the landscape.



*Source: Appendix J of the California Plumbing Code*

| Applicable Spaces | | Climates | | When to Consider | |
|---|---|---|---|---|---|
| Classrooms | ☐ | South Coast | ■ | Programming | ☐ |
| Library | ☐ | North Coast | ■ | Schematic | ☐ |
| Mulit-Purpose / | ☐ | Central | ■ | Design Dev. | ▨ |
| Gym | ☐ | Mountains | ■ | Contract Docs. | ☐ |
| Corridors | ☐ | Desert | ■ | Construction | ■ |
| Administration | ☐ | | | Commissioning | ■ |
| Toilets | ☐ | | | Operation | ■ |
| Other | ☐ | | | | |

Plumbing work is required to divert the gray water from the existing drain lines. All drain lines from gray water sources should link to a common channel that connects to the surge tank. The surge tank contains filters, vents, valves, and pumps. Sand and settling (sedimentation) filters are most commonly used in large applications. Pumps deliver the gray water to toilets and the landscape (if drip irrigation is used).

Gray-water composition varies depending on the water source, plumbing system, and user-specific variables (like cleaning products). At regular concentration levels, few components in gray water will damage trees and shrubs. Few detrimental soil changes will occur from well-managed gray water systems. Gray water contains high levels of grease, fibers, and particles (like dry skin) and is warmer by 5-10°F. Gray water does increase the number of soil organisms- but only slightly. Most harmful effects are more a result of over watering and prolonged saturation of the soil.

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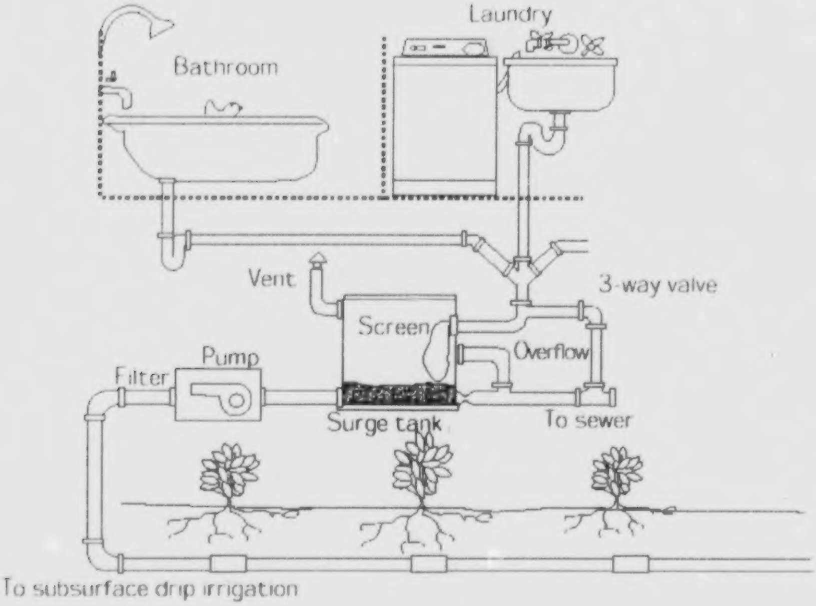


*Source: Appendix J of the California Plumbing Code*

### Applicability

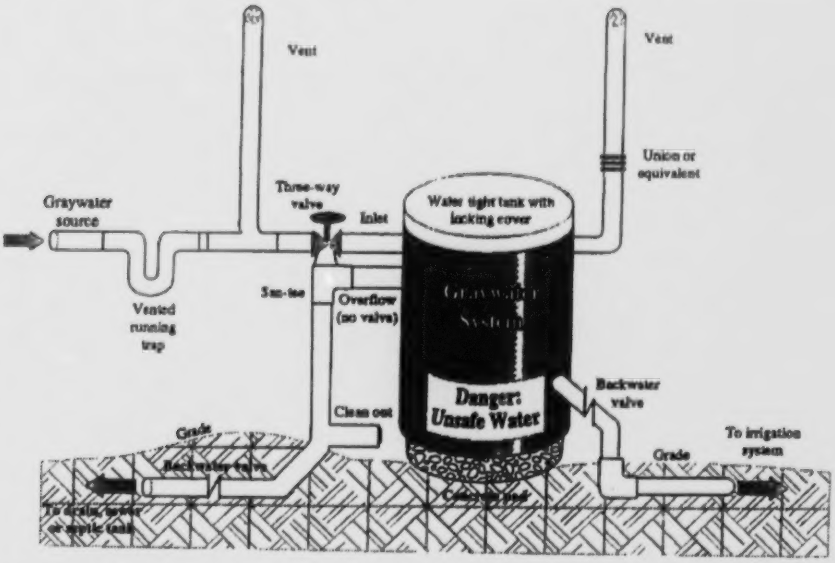
- They are appropriate wherever supplemental irrigation is normally required.
- They are applicable to all climate types but drought-prone climates will especially benefit from a reliable, year-round source for irrigation.
- Do *not* use gray water for plants with limited root areas or on hydroponic plants. Acid loving trees and shrubs (azaleas, begonias, and rhododendrons) may have a problem because gray water is alkaline. Do *not* use gray water on edible plant parts.

### Applicable Codes

In1992, a law legalizing gray water use in the cities and counties of California was passed. The California Department of Water Resources (CDWR) was directed to adopt standards for gray water use. The CDWR standards define gray water as 'untreated single-family residential wastewater from all sources, excluding toilet, kitchen sink, and dishwasher.' It also restricts the use of gray water to subsurface (varies between 8"-12" depending on the soil type) applications. California does not require gray water sampling, monitoring, and treatment.

However, cities and counties in California can accept or reject the state's gray water standards or establish their own, using the state's standards as a base. They even can decide to ban gray water use altogether.

- All sub-surface drip irrigation must take place at least 9" below the soil surface.
- All piping, pumps, and fixtures associated with gray water systems should be clearly labeled along the entire length of the installation.


Vent
Vent
Union or equivalent
Graywater source
Three-way valve
Inlet
Water tight tank with locking cover
Vented running trap
San-tee
Overflow (no valve)
Graywater System
Danger: Unsafe Water
Backwater valve
Clean out
Grade
Backwater valve
To irrigation system
Grade
Concrete pad
To drain, sewer or septic tank

*Source: Department of Water Resources, Division of Planning and Local Assistance, Title 24, Part 5, Appendix G*

## Integrated Design Implications

It's cost effective to have 'integrated' gray water system for new constructions although retrofitting is not a major issue. Plumbing installation and locating the surge tanks require consideration early in the design process.

## Costs

Installation costs for gray water systems can range from several hundred dollars to more than $5,000 for small systems. Generally, systems will have an initial cost between $8-$15 per stored gallon of gray water. The annual operating costs are between $0.15-$0.25 per gallon of capacity.

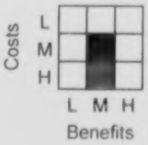


*Table 5 – Types of Systems Currently Available*

| System Type | Source of Graywater | Features | Cost |
|---|---|---|---|
| Low –tech owner or professional installation | Washing machine only | 200 micron mesh filter<br>55 gal garbage can w/locking lid | $400-$800 |
| Medium-tech | Uses all graywater sources | Sump pump to pvc tubing<br>Subsurface drip irrigation<br>200-micron mesh filter<br>(2) 55 gal. storage tanks | $1,000-$1,500 |
| Fully automated Professional installation | Uses all graywater sources | Automatically back-washed sand filter<br>250 gallon storage tanks<br>Pumps at both source and tank/filter<br>3-way valve, backflow preventers<br>Microprocessor controls all flows<br>Backed by potable water | $2,500-$5,000 |

## Benefits

- It conserves water by reusing water from baths and sinks that would have otherwise gone down the drain. At least 30% of total 'used' water is reutilized by such systems.
- Gray water recycling reduces water bills.

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- It ensures drought-proof landscaping. More than half the indoor water can be recycled and this ensures a constant source of water even during shortages. Also the nutrients in the gray water may benefit plants. Valuable plant nutrients such as phosphorous and potassium, are often found in gray water. Graywater use can result in healthier plants and in the reduced application of fertilizers. By leaving the soil surface drier, it may also make for a healthier landscape by reducing disease and pests.
- Using gray water improves the efficiency of applied water because it is delivered to the plants underground- this eliminates runoff, over spray, and evaporation.
- The community benefits from gray water use because it reduces the amount of wastewater that is discharged to the local treatment facility. This has the potential to reduce wastewater treatment costs and may even postpone or avoid the need for flow-related expansions of the facility. Local water and wastewater agencies also experience reduced pumping costs.

### Design Tools

One of the toughest challenges in designing the gray water system is laying out the irrigation system and determining the size of the area to be irrigated. The homeowner or designer must decide which plants can be irrigated with gray water. The size of the irrigated area is determined by the soil type, volume of gray water produced, and by the summer water requirements of the plants. A good rule of thumb is to expect 2-2.5 gallons of water to effectively irrigate 1 ft$^2$ of surface area per day. Estimate the total daily water requirement and assume that only 50% of this estimate will make it into the gray water storage.

### Design Details

- Plumb 'used' water from bathroom sinks, showers, and clothes washers separately from other wastewater. Kitchen sinks may be included if there are no in-sink garbage disposals. This water should drain by gravity into a surge tank.
- Surge tanks should have tightly fitted covers, vent stacks, and overflow drains attached. It should also have a one-way valve to prevent backflow. Install the tank such that the outflow can be gravity driven. If this is not possible, use pumps for delivering water for irrigation. Overflow pipes that redirect water to septic tanks or sewer lines are very important when the field gets saturated.
- The water in the surge tank should be filtered.
- Locate the distribution piping 9" below the soil surface (code required). This will provide adequate decomposition and minimize health risks. Use 'dual' pipes that consist of 1" perforated pipes with 5/16" holes at 6" intervals lodged in pipes of larger diameters with slits at the bottom.
- Provide several independent drain areas with valves for alternate distribution.
- Use a check valve between the pump and outflow piping to restrict the gray water flow in one direction.
- It is a good practice to label and mark all piping, fixtures, and pumps that comprise a gray water system.

### Operation and Maintenance Issues

The success of gray water systems is completely dependent on careful operation and periodic maintenance. The following guidelines should be strictly followed for health and safety reasons.

- Paint thinners, paints or pesticides should never be washed down the drain, and substances such as ammonia and chlorine should find their way into gray water plumbing in very limited quantities only.
- While most detergents can be used with gray water systems, there are several important exceptions and several cautions. Products that contain boron should not be used. Boron has been shown to be very toxic to most plants. Use biodegradable soaps as far as possible.

- If salt buildup in the landscape is a concern (it should be in most cases) it is better to use liquid detergents than powdered detergents. Powdered detergents contain excessive amounts of sodium.
- Chlorine is extremely toxic to plants, but it has not generally been a problem in gray water irrigation. This may be because chlorine breaks down fairly rapidly and its effects may also be dissipated or diluted in the soil. Having some residual chlorine present in the surge tank to minimize bacteria buildup also appears to be a benefit. Chlorine bleach may damage plants if it touches the foliage.
- Gray water should not come in contact with the edible portion of fruits and vegetables (for instance, with root vegetables, such as carrots, radishes, potatoes, and beets).
- Gray water should not be sprayed, allowed to puddle, or run off property.
- Gray water should be rotated with fresh water to leach out any harmful build-up. Biodegradable soaps appear to have the least harmful effects.

### Commissioning

For safety reasons, involve a soil engineer (or other experts) to assess available soil and the feasibility of the system based on soil quality. All purchased equipment should be accompanied by detailed installation information and all equipment should be professionally installed.

### Example

Windsor High School, Sonoma County recently completed construction incorporating reclaimed water for on-site irrigation.

### References / Additional Information

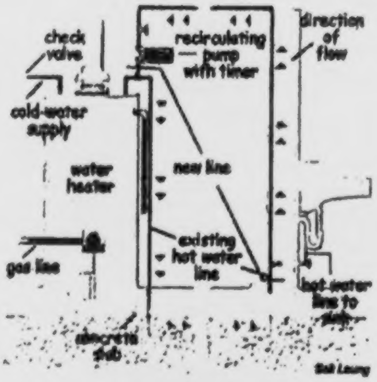
WaterWiser- The Water Efficiency Clearinghouse
http://www.waterwiser.org

EPA Office of Water, U. S. Environmental Protection Agency, www.epa.gov/OW

Guiding Principles of Sustainable Design (Chapter 8), National Park Service
http://www.nps.gov/dsc/dsgncnstr/gpsd

Water Alliance for Voluntary Efficiency (WAVE), http://es.epa.gov/partners/wave/wave.html

# Guideline OS5: Timers for Recirculating Hot Water Systems



Source: *http://www.todayshomeowner.com/*

Source: *http://www.lainginc.com/*

| Applicable Spaces | | Climates | | When to Consider | |
|---|---|---|---|---|---|
| Classrooms | ■ | South Coast | ■ | Programming | ☐ |
| Library | ☐ | North Coast | ■ | Schematic | ☐ |
| Multi-Purpose / Gym | ■ | Central | ■ | Design Dev. | ☐ |
| | | Mountains | ■ | Contract Docs. | ☐ |
| Corridors | ☐ | Desert | ■ | Construction | ☐ |
| Administration | ■ | | | Commissioning | ■ |
| Toilets | ☐ | | | Operation | ☐ |
| Other | ■ | | | | |

## Recommendation

Use recirculation timers to control circulation of hot water based on demand. Use separate hot water systems for areas with significantly different demand patterns.

## Description

Recirculating hot water systems connect to your hot water pipe and constantly circulate hot water through the pipes from the heater to the furthest fixture and then back to the heater, making warm water immediately available upon turning the tap. Large facilities use recirculating hot water systems- this results in heat losses through the distribution piping. Installing timers ensures that hot water circulates only during times of need. Operating the system only during these times greatly reduces the heat loss through the distribution piping as well as the daily pumping load.

## Applicability

Timers are applicable to large facilities where hot water is recirculated. Timers will work effectively only when the hot water demand for a facility can be predicted accurately (as is the case with classrooms and school administrative areas).

## Applicable Codes

The service hot water system should meet all the requirements of Title 24 Section 113 – Mandatory Requirements for Service Water Heating Systems and Equipment. Section 113 (b) 2 also states that all pumps for circulating systems should have a control capable of automatically turning off the circulating pump when hot water is not required (exception- residential occupancies).

## Costs

Timers for recirculating systems are priced between $40-$50.

| Costs \ Benefits | L | M | H |
|---|---|---|---|
| L | | ■ | |
| M | | | |
| H | | | |

## Benefits

- Timers greatly reduce heat losses through distribution piping.
- Daily pumping loads are reduced considerably.

BEST COPY AVAILABLE

## Cost Effectiveness

Timers are very cost effective and have a 2-5 year payback period.

## Design Tools

None.

## Design Details

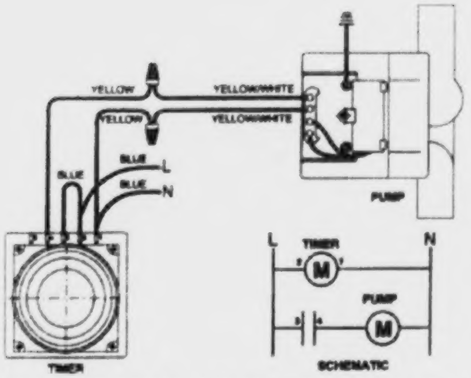
- Most schools are ideal candidates for using timers because of the predictability of classroom schedules. Set the system to operate only between classes, just before and after the school day, and during lunch periods.
- Administrative areas, locker rooms, and other areas may have a demand schedule different from that of the classroom facility. Separate hot water systems or gas-powered instantaneous water heaters can be used to accommodate these areas. Avoid using timers for areas with random and intermittent schedules.
- Consider using thermostats connected in series with the timers. The thermostat turns off the pump when the water in the pipes reaches a certain temperature. So once the water in the pipe is hot, the pump turns off. If the timer and thermostatic controls are installed together in series, the circulator operates only at the preset clock times and only when the temperature conditions of the thermostat are met. That is, if either the timer control or the thermostatic control switch is open (off), the circulator will not operate. This results in additional savings.

## Operation and Maintenance Issues

- Adjust initial timer schedule based on observed or monitored demand data. Schedules may vary from school to school and it is important to fine-tune the timer settings based on specific demand patterns.
- Check hot water supply every 6 months to ensure that the timer is functioning as expected.
- Always set the timer switch to the actual time by turning the programming ring in the direction of the arrow until the timing arrow points to the actual time on the ring.
- In case of power outage the timer will not keep time. After power has been restored, the correct time of day must be reset by rotating the programming ring in the direction of the arrow until the timing arrow points to the actual time on the ring.

## Commissioning

- If installing a thermostat along with the timer, ensure that the two devices are installed in series.
- After wiring is completed and checked, install the timer control unit onto the terminal box bracket of the pump and reinsert the terminal box screw. Be careful not to bind or leave exposed any terminal box wires.


YELLOW
YELLOW/WHITE
YELLOW
YELLOW/WHITE
BLUE
BLUE
L
BLUE
N
PUMP
TIMER
L
TIMER
N
M
PUMP
M
SCHEMATIC

WIRING DIAGRAM FOR TIMER CONTROL ONLY

*Source: http://www.plumbingsupply.com/grundtimer.html*

## Example(s)

## References / Additional Information

http://www.eren.doe.gov/buildings/consumer_information/water/waterques.html#13

http://www.lainginc.com/instant.htm

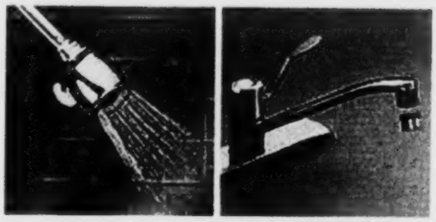
http://www.plumbingstore.com/circpump.html#faq

Questions & Answers, Today's Homeowner, 2 Park Ave., New York, NY 10016, fax: 212/725-3281, e-mail: questions@todayshomeowner.com

# Guideline OS6: Efficient Terminal Devices

## Recommendation

Use low-flow toilets and low-flow devices on all terminals like faucets and showerheads. Use automatic faucets for controlling wastage of clean water.



*Low-flow showerhead and faucet aerator*

*Source: Las Vegas Valley Water District, http://www.lvvwd.com/conservation/free_products.html*

| Applicable Spaces | | Climates | | When to Consider | |
|---|---|---|---|---|---|
| Classrooms | ☐ | South Coast | ■ | Programming | ☐ |
| Library | ☐ | North Coast | ■ | Schematic | ☐ |
| Mulit-Purpose / Cafeteria | ■ | Central | ■ | Design Dev | ☐ |
| Gym | ☐ | Mountains | ■ | Contract Docs | ☐ |
| Corridors | ☐ | Desert | ■ | Construction | ■ |
| Administration | ☐ | | | Commissioning | ☐ |
| Toilets | ■ | | | Operation | ☐ |
| Other | ■ | | | | |

## Description

Installing low-flow devices is simple and cost effective. In 1995, the National Energy Policy Act mandated the use of toilets that use no more than 1.6 gallons of water per flush (reduced from 3.5 gallons per flush). Low-flow toilets use various technologies like large drain passages, redesigned bowls, and tanks for increased functionality and easier wash-downs.

Older showerheads typically deliver 4-5 gpm of water. Newer showerheads are more efficient and follow the National Energy Policy Act of 1992 that allows a maximum water flow rate of 2.5 gpm (at standard water pressure of 80lb/in$^2$). Showerheads should use aerator technology and multiple flow settings to save water. Conventional bathroom faucets use 3-7 gpm. New faucets, designed to meet federal codes, use a maximum of 2.5 gpm (at 80 psi), although some are being designed to use 1.5 gpm or less. The new low-flow faucets essentially operate in one of two ways: aeration or laminar flow. In laminar flow faucets, the water travels in parallel streams producing a clear flow of water without being mixed with air (as in aeration). This produces superior wetting ability over that of aerating faucets. Laminar flow faucets are somewhat more expensive than aerating types. Conventional faucet aerators do not compensate for changes in inlet pressure, so the greater the water pressure, the more water you use. New technology compensates for pressure and provides the same flow regardless of pressure. Aerators are also available that allow water to be turned off at the aerator itself.

Some low-flow faucets are metered-valve type- they deliver a fixed quantity of water and then shut off automatically. Other types of automatic faucets include self-closing and sensored. Sensored faucets, either infrared or ultrasonic, are designed to turn on when a user's hands are placed under the faucet, and turn off when the hands are removed.

## Applicability

Low-flow technology is applicable to all terminal devices that deliver water.

## Applicable Codes

Low flow plumbing fixtures must meet the appropriate American National Standards Institute (ANSI) standards listed by the International Association of Plumbing and Mechanical Officials (IAPMO).

## Costs

A good quality, low-flow showerhead will cost $10 to $20. Low-flow faucet aerators cost $4.50-$8. A sensored faucet is expensive and may cost up to $160/fixture more than the regular faucets.

| Costs | L | M | H |
|---|---|---|---|
| L | | ■ | ▨ |
| M | | | |
| H | | | |

Benefits

## Benefits

- A low-flow device will pay for itself in energy saved within 4-8 months.
- Installing low-flow showerheads and faucet aerators can save significant amounts of hot water. Low-flow showerheads can reduce hot-water consumption for bathing by 30% while still providing a strong, invigorating spray.
- Water consumption is reduced by 15%-20% resulting in lower environmental costs. This also reduces the load on wastewater plants. Easy installation procedures make low-flow plumbing fixtures feasible for retrofitting. It is estimated that low-flow toilets alone could save up to 2,000 gallons of water per person.

## Design Tools

None.

## Design Details

- Use aerators that deliver 0.5-1 gpm of water for bathroom faucets.
- Use aerators with higher flow rates (2-3 gpm) for sink faucets that will be used for intensive washing purposes.

## Operation and Maintenance Issues

Faucets should be periodically checked for leaks and repaired as needed. Leaky faucets can waste enormous amounts of water (tens of gallons in a single day).

Faucet aerators need to be checked periodically for clogging, some models clog more easily than others and may need to be cleaned too often to be effective. Some aerators may cause unacceptable performance or the perception of poor performance, resulting in an increase in water use.

## Commissioning

Installation of low-flow plumbing fixtures is similar to that of conventional fixtures. Most of these fixtures require no special connections or fittings. Low quality showerheads may simply restrict water flow, which often results in poor performance.

## Example(s)

## References / Additional Information

American Water Works Association, 1401 New York Ave. NW, Suite 640, Washington, DC 20005 USA, TEL 202-628-8303, http://www.awwa.org

Plumbing Manufacturers Institute (PMI), 800 Roosevelt Road, Building C, Suite 20, Glen Ellyn, IL, 60137, 708/858-9172, http://www.pmihome.org

Mister Miser Urinal, 4901 North Twelfth Street, Quincy, IL 62301, 217-228-6900, info@mistermiser.com

# Guideline OS7: Waterless Urinals

### Recommendation

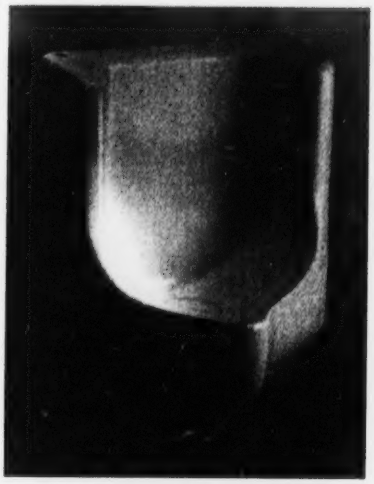
Install waterless urinals wherever applicable.

### Description

The waterless urinal systems have some innovative features that distinguish the product from the conventional urinal systems available today and are being used in schools since 1993. The products 'look-like, feel-like and work-like a conventional urinal system except for one important difference: they do not require precious water to operate.'

The system is consists of three main components: a polypropylene trap insert, a sealant liquid, and a reinforced fiberglass urinal body.

The primary component of the product is the trap cartridge. This cartridge 'traps' the bio-degradable sealant liquid. This second component is lighter than other liquids. It floats on and seals the contents from the atmosphere. This special liquid allows urine to sink through its layer, eliminating the odors associated with urine and creating a pleasant and odor-free environment. Urine is 90% water and readily flows down and falls through the trap. This trap design allows immersed urine to be discharged into the drain without using any mechanical parts.

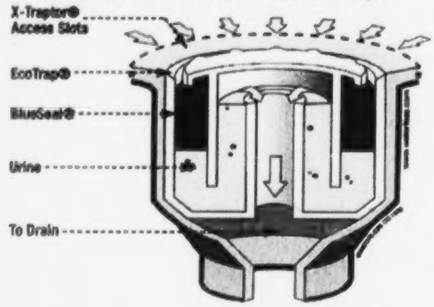


*Source: Waterless Co.*

| Applicable Spaces | | Climates | | When to Consider | |
|---|---|---|---|---|---|
| Classrooms | ☐ | South Coast | ■ | Programming | ☐ |
| Library | ☐ | North Coast | ■ | Schematic | ☐ |
| Mulit-Purpose / Cafetena | ☐ | Central | ■ | Design Dev | ☐ |
| Gym | ☐ | Mountains | ■ | Contract Docs | ☐ |
| Corridors | ☐ | Desert | ■ | Construction | ■ |
| Administration | ☐ | | | Commissioning | ☐ |
| Toilets | ■ | | | Operation | ☐ |
| Other | ☐ | | | | |

The system requires only about 3 oz of sealant liquid per charge to operate and will last for about 1500 sanitary uses. The liquid is then simply replenished. The trap needs to be replaced 3-4 times a year depending on frequency of use.

**Cross - Section of the Patented Vertical EcoTrap®**



*Source: Waterless Co.*

### Applicability

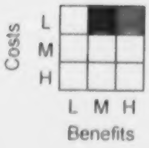
Waterless urinals are applicable to all restroom modernizations and new construction.

## Applicable Codes

ANSI Z124.9, UPC®, CSA®

## Costs

Costs for waterless urinals are comparable to regular manual flushed urinals and are less than automatic sensor flushed urinals.



## Benefits

Some of the benefits of waterless urinals include:

- Easy maintenance because there are no moving parts involved. It has durable, break-resistant fiberglass construction.
- Flushometer and valve replacements are common problems for flush urinals. Such repairs are not an issue for waterless urinals.
- Waterless urinals are simple to install and use. Replacing existing conventional urinals with waterless products is also relatively simple to accomplish. It easily adapts to existing 2" plumbing waste lines.
- They have a short payback period of 1-4 years.
- They save water as well as added cost of treating water. Fresh water supply will be preserved and can be applied in a more effective and meaningful way. Less water released into the treatment process implies reduced environmental impact and the pollution.
- Waterless urinals significantly reduce clogging and prevent overflows.

## Cost Effectiveness

The payback period for the system is 1-4 years. Savings due to waterless urinals are estimated between $150-$330/urinal/year depending on factors like number of users, cost of water, cost of sewer, volume of water use, and maintenance. The Bureau of Reclamation estimates a 3-year payback.

## Design Tools

None.

## Design Details

None.

## Operation and Maintenance Issues

- The smooth, simple design of the waterless system is easy to clean and maintain. Also, there are no costly repairs usually associated with the mechanical components of flush valves.
- The trap cartridge should be replaced two or four times per year, depending on the frequency of use. Use the tool included with the product.
- The sealant liquid is bio-degradable and the trap cartridge should be recycled.

## Commissioning

- The drain line should be clear before installation. This may require snaking the drain line.

## Example(s)

Waterless urinals have been installed in many schools, including:

San Dieguito UHSD, Encinitas, CA, Ramona USD, Ramona, CA, San Diego City Schools, San Diego, CA, Carlsbad USD , Carlsbad, CA, Newport Mesa USD, Costa Mesa, CA, and Alameda USD, Alameda, CA.

### References / Additional Information

Waterless Co., 1223 Camino Del Mar, Del Mar, CA 92014 USA, klaus@waterless.com, http://www.waterless.com/

Falcon Waterfree Technologies, 10900 Wilshire Blvd., 15th Floor, Los Angeles, California 90024 USA, http://www.waterlessurinals.com/

# Guideline OS8: Relocatable Classrooms

*This modular relocatable structure is a prototype designed by Southern California Edison and contains a variety of high performance features such as daylighting, high indoor air quality, significant energy savings, and resource efficient materials.*

*Photo courtesy of Southern California Edison.*

### Recommendation
Follow measures to increase the indoor environmental quality of school portables.

### Description
Portables should contain appropriate building and indoor surface materials and properly designed ventilation systems to minimize the presence of indoor pollutants. Commissioning and regular maintenance should be conducted to ensure quality of the indoor environment.

### Applicability

| Applicable Spaces | | Climates | | When to | |
|---|---|---|---|---|---|
| Classrooms | ☐ | South Coast | ■ | Programming | ☐ |
| Library | ☐ | North Coast | ■ | Schematic | ☐ |
| Mulit-Purpose / Cafeteria | ☐ | Central | ■ | Design Dev | ☐ |
| Gym | ☐ | Mountains | ■ | Contract Docs | ☐ |
| Corridors | ☐ | Desert | ■ | Construction | ☐ |
| Administration | ☐ | | | Commissioning | ☐ |
| Toilets | ☐ | | | Operation | ☐ |
| Other | ■ | | | | |

### Applicable Codes
The State Department of General Services (DGS) issues specifications on "Building, Classroom, Prefabricated, Relocatable General Requirements", which outlines the DGS requirements for the State Portable Classroom Program. The demand generated by the Class Size Reduction Program exhausted the available inventory of state lease program relocatable classrooms. Many school districts will instead obtain relocatable classrooms directly from manufacturers. Although all classroom units manufactured for California must conform to the Title 24 Building Standard Code, these standards are not specific for "portables". Hence these relocatable units may not adhere to the DGS specifications, and their design and quality can vary.

### Integrated Design Implications
Portables are self contained units. The choices of fenestration and HVAC will affect the indoor environment in the same way as permanent buildings.

### Costs
Cost figures for high performance relocatable classrooms are still being collected based on prototypes developed by Southern California Edison and Pacific Gas and Electric.

| Costs | L | M | H |
|---|---|---|---|
| L | ■ | ☐ | ☐ |
| M | ☐ | ☐ | ☐ |
| H | ☐ | ☐ | ☐ |

Benefits

### Benefits
High performance relocatable classrooms are little buildings and the have the same benefits of complete schools.

### Design Tools
See other guidelines.

## Design Details

- The DGS bid specification for Relocatable Classrooms require that HVAC systems must supply 480 cfm of total outdoor air.
- When specifying a new relocatable classroom, ensure that the HVAC system can: (a) provide the minimum outdoor air of 480 cfm; and (b) heat and cool this outdoor air at design outdoor temperatures for the specific geographic location where each classroom is installed. Some manufacturers of relocatable units do not include outdoor air intakes in their standard classroom models. It is important that an additional "outdoor air kit" be ordered for this purpose. Further, installation of an outdoor intake must be specified as part of the exhaust system. Lack of an exhaust in the HVAC system with an outdoor air intake will result in room pressurization, reduced outdoor air flow rates, and lower efficiency of removal of pollutants from the room.
- Outdoor air should be supplied continuously when a classroom is occupied. Demand-controlled HVAC package systems often used in relocatable classrooms typically operate only when the temperature of a space is different from the thermostat's set point. In order to provide a continuous outdoor air supply, it is important to ensure that the HVAC thermostats are set in the "on" or continuous mode when occupied.
- Avoid package wall-mounted HVAC systems because of their excessive noise. Split systems are recommended.
- Particle filters are needed for protection of HVAC components and reduction of airborne dust, pollens and microorganism form recirculated and outdoor air streams. For relocatable classrooms, the DGS requires installation of a replaceable filter in the HVAC system. ASHRAE Standard 62-1989R requires filters with minimum of 25-30% dust spot efficiency (ASHRAE Standard 52.1) or >60% efficiency (ASHRAE Standard 52.2 for 3 micron particle). Where system design can accommodate them, filters with >65% efficient=cy for 1 to 3 micron particles will improve IAQ with respect to particles.
- Flooring materials. The DGS State Portable Classroom Program requires that units be carpeted except in certain areas, such as bathrooms. When carpets are specified, use carpets that have been certified under the Carpet and Rug Institute's Indoor Air Quality Labeling Program.
- Site classroom away from locations where: (a) vehicles idle, (b) water accumulates after rains, and (c) electric/magnetic fields (EMF) are high.
- Ensure that at least one supply air outlet and return air inlet are located in each enclosed area.
- Ensure that building air intakes are located away form any exhaust outlet(s) or other contaminant sources.
- Specify operable windows, to provide user-controlled ventilation when needed.
- Do not use carpet in entryways to classrooms with direct outdoor access. Otherwise, supply waterproof mats over carpeted entryways for drying of clothing and umbrellas.
- Check that special-use classrooms (e.g., for chemistry, biology, fine arts, etc.) have local exhaust ventilation (e.g., hoods or window fans).
- Locate HVAC and air handler units as far away as possible from teaching areas.
- Have insulation installed only on the outside surfaces (not inside) of air ducts.
- Ensure that HVAC ducts and plenums have easy access for inspection and cleaning.
- Specify that building materials used in construction are certified as "low-emitting" for volatile organic compounds.

## Operation and Maintenance Issues

- Provide training on operation and maintenance of new HVAC equipment to appropriate staff.
- Be certain that operation and maintenance documentation is kept readily accessible to staff servicing the system.

- Maintain documentation of completed tasks.
- Allocate sufficient staff time and funds for maintenance.
- Instruct teachers and staff on proper use and settings of thermostat and ventilation controls – provide each classroom with hardcopy (plastic-covered) instruction sheets

Establish a regular and timely plan for testing, inspecting, and performing specific maintenance tasks:

- Inspect roofs, ceilings, walls, floor, and carpeting for evidence of water leakage or infiltrations, and for mold and mildew growth or odor. Replace water damaged materials.
- Inspect air supply outlets and return air inlets, to ensure that they are open, operable and unobstructed.
- Check airflows rates at the outlets and inlets periodically.
- Inspect air plenums for mold growth, excess dirt, etc.
- Establish a periodic air filter replacement schedule.
- Clean condensate pans (monthly) and do not allow free standing water to accumulate.
- When carpets are cleaned, ensure that they dry thoroughly as soon as possible after the process is done.
- Provide for the proper storage of cleaning/janitorial supplies
- Maintain documentation of completed tasks.

### Commissioning.

Prior to use of any new relocatable units by staff or students, operate HVAC systems at their maximum outdoor air intake rate continuously for several days. Start the "flush out" as soon as the HVAC system is operational, and continue after furniture installation. During this period, do not recirculate return air.

Do no "bake-out" the unit. "Back-out" is defied as increasing temperatures up to 100°F in order to "artificially age" building materials. The effectiveness has not been proven and they may in fact damage parts of the HVAC system or building components.

Continue "flush-out" ventilation during periods of first use. Efforts to minimize exposures to school children and staff should continue in the weeks following construction. Emissions of VOCs are highest during this period. Flush-out periods of 1-2 weeks are recommended, although longer periods may be required. For the first days to weeks of occupant use, continue to operate HVAC systems at the maximum outdoor air setting. Finally, monitor occupants' comfort, and follow-up complaints to identify problems early.

Establish an Integrated Pesticide Management plan. For a quick reference guide, see *Pest Control in the School Environment: Adopting Integrated Pest Management*, Report IPA 735-f-93-012.

### Example

Rethinking the Portable Classroom
A demonstration project of Southern California Edison, Design & Engineering Services

### References / Additional Information.

*IAQ Tools for Schools Action Kit.* U.S. EPA Indoor Air Quality Information Clearinghouse, 1-800-438-4318.

*Indoor Air Quality: A guide for Educators.* California Department of Education, School Facilities Planning Division. 916-322-2470

*Building Air Quality: A Guide for Building Owners and Facility Managers.* Superintendent of Documents 202-512-2250.

*Indoor Air Quality / School Facilities Documents.* (a set of 15 documents, such as "Maintaining Acceptable IAQ During the Renovation of a School", "Maintenance of HVAC systems and IAQ in Schools"),Maryland State Department of Educations, Schools Facilities Branch 410-767-010

# Appendix

## High Performance Schools Best Practices Manual

Version 1.0
March 1, 2001

A Project of:

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# Preface

## Background

This is a unique period in California history. The state, already educating 1 out of every 8 students in America, has seen historical enrollment rates four times higher than national averages. Hundreds of schools a year are being built to house the 100,000 new students per year moving into the system and to accommodate state-mandated class-size reductions. The current infrastructure is aging and over 30% of existing facilities are in need of major renovation. At the same time, California schools are spending nearly $450 million per year on energy[1] in a time of rising concern over energy supplies and tight school budgets. These figures illustrate an enormous opportunity for our state's school districts to build the next generation of school facilities that improve the learning environment while saving energy, resources, and money.

The goal of this Best Practices Manual is to create a new generation of high performance school facilities in California. The focus is on public schools and levels K-12, although many of the design principals apply to private schools and higher education facilities as well. High performance schools are healthy, comfortable, energy efficient, resource efficient, water efficient, safe, secure, adaptable, and easy to operate and maintain. They help school districts achieve higher test scores, retain quality teachers and staff, reduce operating cost, increase average daily attendance (ADA), reduce liability, while at the same time being friendly to the environment.

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[1] These costs are based on data prior to the California energy crisis, which begin during the winter of 2000-2001. During this period, wholesale energy costs by a factor of eight. Eventually, some or all of these costs will be passed on to schools and other utility customers.

## Best Practices Manual Organization

This Best Practices Manual is split into three volumes:

- Volume I addresses the needs of school districts, including superintendents, parents, teachers, school board members, administrators, and those persons in the school district that are responsible for facilities. These may include the Assistant Superintendent for Facilities (in large districts), buildings and grounds committees, energy managers, and new construction project managers. Volume I aims to describe *why* high performance schools are important, *what* components are involved in their design, and *how* to navigate the design and construction process to ensure that they are built.
- Volume II contains design guidelines for high performance schools. These are tailored for California climates and are written for the architects and engineers who are responsible for designing schools as well as the project managers who work with the design teams. Volume II is organized by design disciplines and addresses specific design strategies for high performance schools.
- Volume III is the CHPS Eligibility Criteria. These criteria are a flexible yardstick that precisely defines a high performance school so that it may qualify for supplemental funding, priority processing, and perhaps bonus points in the state funding procedure. School districts can also include the criteria in their educational specifications to assure that new facilities qualify as high performance.

The Best Practices Manual is supported by the CHPS website (www.chps.net), which contains research papers, support documents, databases and other information that support the Best Practices Manual.

### CHPS Stakeholders

California Department of Education (CDE)

Coalition for Adequate School Housing (CASH)

Division of the State Architect (DSA)

Office of Public School Construction (OPSC)

California Energy Commission (CEC)

California Integrated Waste Management Board (CIWMB)

Los Angeles Department of Water and Power (LADWP)

Pacific Gas and Electric Company (PG&E)

Sacramento Municipal Utility District (SMUD)

San Diego Gas and Electric (SDG&E)

Southern California Edison (SCE)

Southern California Gas Company (SoCalGas)

California Air Resources Board (CARB)

California Department of Health Services (DHS)

Natural Resources Defense Council (NRDC)

## Who is CHPS

In November 1999, the Energy Commission called together Pacific Gas and Electric Company, San Diego Gas and Electric, and Southern California Edison to discuss the best way to improve the performance of California's schools. CHPS was formed out of this partnership and has grown to include a diverse range of government, utility, and non-profit organizations with a unifying goal: to improve the quality of education for California's children.

## Acknowledgements

A great number of people have contributed to the development of this manual. Charles Eley is the CHPS Administrator and served as the technical editor. Kathleen O'Brien and Jane Simmons (both of O'Brien

and Company) are the primary author of the chapters on materials, site planning and general conditions. Jim Benya (Benya Lighting Design) and Tom Tolen (TMT Associates) wrote the lighting chapter. Barbara Erwine (Cascadia Conservation) and Lisa Heschong (Heschong Mahone Group) are authors of the daylighting chapter. Erik Kolderup, Joe Kastner, Anamika (all of Eley Associates), and Adam Wheeler (Control Group) wrote the HVAC and mechanical chapters. Randy Karels (Eley Associates) has worked with CHPS from the beginning and coordinated and edited Volumes I and III. Deane Evans of the Sustainable Buildings Industries Council (SBIC) developed the discussion guide and prepared much of the material on cross-cutting issues.

In addition to the primary authors, Anthony Bernheim (SMWM Architects), Lynn N. Simon (Simon & Associates), and Gary Mason (Wolfe Mason Associates) serve on the CHPS Technical Advisory Group and have helped develop and review content. John Guill (Quattrocchi / Kwok Architects), Dennis Dunston (HMC Architects), Kerry Parker (TMAD Engineers) and George Wiens (WLC Architects) serve on the Professional Advisory Group, a group of architects and engineers active in the design of California schools. Both advisory groups have made significant contributions to the document and to the overall direction of CHPS.

The CHPS stakeholders have not only made the Best Practices Manual possible through their funding, they have also contributed countless hours to reviewing the document and providing direction. Special thanks to Manuel Alvarez, Gregg Ander, Chuck Angyal, Duwayne Brooks, Richard Conrad, Don Cunningham, Julia Curtis, Ray Darby, Grant Duhon, Lisa Fabula, Chip Fox, Kathy Frevert, Randall Higa, Greg Golick, Tony Hesch, Jan Johnson, Oliver Kesting, Kathleen McElroy, Daryl Mills, Bill Orr, Dana Papke, Jim Parks, Robert Pernell, Tom Phillips, Richard Sheffield, Mike Sloss, Chip Smith, Lisa Stoddard, and Jed Waldman.

# Table of Contents

**Preface** ii
- Background ii
- Best Practices Manual Organization iii
- Who is CHPS iii
- Acknowledgements iii
- Table of Contents v

**Appendix A – Job Site Specifications** 1
- Section 01501 – Indoor Air Quality Construction Plan 1
- Section 01500 – Waste Reduction 4
- Section 01503 – Site Protection Plan 9
- Waste Reduction Plan 11

**Appendix B – Calculating Cost-Effectiveness** 12
- Introduction 12
- Other Issues 14

**Appendix C – A Field-Based Thermal Comfort Standard for Naturally Ventilated Buildings** 18
- Introduction 18
- Adaptation In Buildings 19
- Research Methods 20
- Thermal Comfort In Air-Conditioned Vs. Naturally Ventilated Buildings 20
- An Adaptive Comfort Standard For Naturally Ventilated Buildings 24
- Conclusions 26
- References 27

**Appendix D – Energy Cost and IAQ Performance of Ventilation Systems and Controls** 29
- Executive Summary 29
- Purpose And Scope of this Report 29
- Methodology 32
- Limitations 33
- Issues Addressed in the Project 33
- Key Results 35
- Discussion 37
- Summary 44
- Bibliography 44

**Appendix E - Lighting Design Supplement** 57
- IESNA Lighting Design Process 57
- Design Issues 58
- Light Sources 59
- Luminaires 64
- Lighting Controls 68

**Appendix F - Daylighting and Fenestration Design Supplement** 71
- Optimizing the Aperture Size 71
- Glazing Products 72
- Links with Other High Performance Design Measures 76
- Other Design Considerations for Daylighting and Fenestration Design 77

# APPENDIX A – JOB SITE SPECIFICATIONS

## Section 01501 – Indoor Air Quality Construction Plan

### GENERAL

#### SUMMARY

Section Includes:

- Description of an Indoor Air Quality (IAQ) Construction Plan
- IAQ Construction Requirements

Related Sections: Site protection specifications included in this section should be coordinated with the following sections of the Project Manual, including:

- Division 9: Finishes
- Division 15: Mechanicals

Coordinate with related temporary controls, in particular:

- Section 01572: Sustainable Job Site Operations – Waste Reduction
- Section 01573: Sustainable Job Site Operations – Site Protection

### INDOOR AIR QUALITY

Goals: The owner has set the following indoor air quality goals for jobsite operations on project, within the limits of the construction schedule, contract sum, and available materials, equipment, products and services. Goals include:

- Prevent residual problems with indoor air quality in the completed building.
- Protect workers on the site from undue health risks during construction.

#### INDOOR AIR QUALITY PLAN

Within fourteen (14) days after receipt of Notice of Award and prior to any waste removal by the Contractor from the Project, the Contractor shall develop and submit to the Owner for review a healthy indoor air quality plan. This plan shall be Part II of a "Sustainable Job Site Operations Plan."

- List of IAQ protective measures to be instituted on the site
- Schedule for inspection and maintenance of IAQ measures

#### SUBSTITUTIONS

Should the Contractor desire to use procedures, materials, equipment, or products that are not specified but meet the intent of these specifications to protect air quality on the site, the

Contractor shall propose these substitutions in accordance with Substitutions and "Or Equal" in General Requirements.

## PRODUCTS

### MATERIALS

Low emitting products have been specified in appropriate sections.

## EXECUTION

### ALL PHASES

- The Contractor is minimally required to meet or exceed minimally the minimum requirements of the Sheet Metal and Air Conditioning National Contractors Association (SMACNA) IAQ Guidelines for Occupied Buildings Under Construction, 1995 to:
- Protect the ventilation system components from contamination, OR provide cleaning of the ventilation components exposed to contamination during construction prior to occupancy.
- Provide a continuous ventilation rate of one air change per hour minimum during construction, OR, conduct a building flush-out with new filtration media at 100% outside air after construction ends (following issuance of Occupancy Certificate) and prior to occupancy for seven days (one week). Provide a minimum of 85% filtration (as determined by ASHRAE Standard 52.1-1992) on any return air systems operational during construction, and replace filtration media prior to occupancy.
- During installation of carpet, paints, furnishings, and other VOC-emitting products, provide supplemental (spot) ventilation for at least 72 hours after work is completed. Preferred HVAC system operation uses supply air fans and ducts only; exhaust provided through windows. Use exhaust fans to pull exhaust air from deep interior locations. Stair towers and other paths to exterior can be useful during this process.
- Conduct regular inspection and maintenance of indoor air quality measures including ventilation system protection, and ventilation rate.
- Require VOC-safe masks for workers installing VOC-emitting products (interior and exterior) defined as products that emit 150 gpl or more UNLESS local jurisdiction's requirements (Canadian or US) are stricter, in which case the strictest requirement shall be followed for use of VOC-safe masks.
- Use low-toxic cleaning supplies for surfaces, equipment, and worker's personal use. Options include several soybean-based solvents and cleaning options (SoySolv) and citrus-based cleaners.
- Use wet sanding for gypsum board assemblies. Exception: Dry sanding allowed subject to owner approval of the following measures:

Full isolation of space under finishing

Plastic protection sheeting is installed to provide air sealing during the sanding

Closure of all air system devices and ductwork

Sequencing of construction precludes the possibility of contamination of other spaces with gypsum dust

Worker protection is provided

Use safety meetings, signage, and subcontractor agreements to communicate the goals of the construction indoor air quality plan.

END OF SECTION

# Section 01500 – Waste Reduction

SECTION 01500
SUSTAINABLE JOB SITE OPERATIONS PLAN
WASTE REDUCTION

## GENERAL

### SUMMARY

Section Includes:

- Description of a Job-Site Waste Reduction Plan
- Waste Reduction Requirements for Demolition
- Waste Reduction Requirements for New Construction

Related Sections: Waste reduction (recycling, reuse, and salvage) specifications included in this section should be coordinated with the following sections of the Project Manual, including:

- Section 02000 - Site Demolition
- Section 02000 - Asphaltic Paving, (Concrete/Asphalt Reuse)
- Section 06000 - Rough Carpentry (Wood)
- Section 09000 - Gypsum Board
- Division 15000 - Mechanical (Cardboard and Metals)
- Division 16000 - Electrical (Cardboard)

Coordinate with related temporary controls, in particular:

- Section 01501 - Sustainable Job Site Operations – Site Protection
- Section 01502 - Sustainable Job Site Operations – Indoor Air Quality

## JOB SITE WASTE REDUCTION

**Goals:**

Owner has set the following waste reduction goals for the project, within the limits of the construction schedule, contract sum, and available materials, equipment, products and services. These goals are consistent with:

- Executive Order 13101
- The 1997 "Statement on Voluntary Measures to Reduce, Recover, and Reuse Building Construction Site Waste" released by the American Institute of Architects and the Associated General Contractors of America.
- The California Integrated Waste Management Board (CIWMB)'s market development plan "Meeting the 50 Percent Challenge: Market Development Strategies Through the Year 2000," in which reducing C&D debris is identified as a priority means of achieving the State's mandated diversion goal of 50% by 2000.

- Sample County Ordinance #000, which requires that projects over 10,000 square feet involving construction, remodeling or demolition, must submit a "Solid Waste Management and Recycling Plan" to the Public Works Staff for review and approval.
- The waste reduction goals for this project include:
- Minimizing the amount of construction and demolition (C&D) waste generated.
- Diverting waste created through C&D processes from disposal through reuse (salvage) and recycling. A minimum of 75% by weight of total project demolition waste, and a minimum of 50% by weight of total project new construction waste shall be diverted from landfill.
- Use recycled-content or salvaged building materials.

## DEFINITIONS

- Waste: For the purpose of this section, the term applies to all excess materials, including materials that can be recycled, unless otherwise indicated.
- Construction and Demolition Waste (C&D): Includes all non-hazardous solid wastes resulting from construction, remodeling, alterations, repair, and demolition.
- Proper Disposal: As defined by the jurisdiction receiving the waste. Rules for the Sample County Central Landfill for disposal of construction and demolition material/debris are available from Jane Doe, Department of Public Works at (000-000-0000).
- Hazardous Waste: As defined by local jurisdictions, California Department of Toxic Substances Control, and the California Integrated Waste Management Board.
- Recycling: The process of sorting, cleaning, treating, and reconstituting materials for the purpose of using the material in the manufacture of a new product. Can be conducted on site (as in the case of concrete ground on site for use on the site or elsewhere).
- Recycling facility: An operation that can legally accept materials for the purpose of processing the materials into an altered form for the manufacture of a new product. Recycling facilities have their own specifications for accepting materials.
- Reuse: Making use of a material without altering its form.
- Salvage: Recovery of materials for on-site reuse or donation to a third party.
- Source-separated materials: Materials that are sorted at the site for the purpose of reuse or recycling.

## WASTE REDUCTION PLAN

- Within fourteen (14) days after receipt of Notice of Award and prior to any waste removal by the Contractor from the Project, the Contractor shall develop and submit to the Owner for review a waste reduction plan. A sample form is attached. This plan shall be Part I of a "Sustainable Job Site Operations Plan." Once approved by the owner, the Contractor shall provided copies of the waste reduction plan to the owner's representative, the project architect, the job site foreman, and all subcontractors. In addition, the plan shall be posted on the site in a prominent location.
- The waste reduction plan shall include:
- Estimate of total project waste to be generated, landfills where waste would normally be disposed, tipping fees, and estimated cost of disposal.

- Types and estimated quantities of salvageable materials that are expected to be generated during demolition.
- The method to be used to salvage or reuse these material on-site. Methods shall include one or more of the following options: contracting with a deconstruction specialist to salvage all or most materials generated, selective salvage as part of demolition contractor's work, and reuse of materials on site or in the new structure.
- Types and estimated quantities of recyclable materials expected to be generated during demolition and construction in significant amounts, in particular, wood, concrete, metals, cardboard, and drywall. Other recyclable materials to be generated should be listed as well.
- The method to be used to recycle these materials. Methods shall include one or more of the following options: requiring subcontractors to take materials back for recycling (new construction), contracting with a full service recycling service to recycle all or most materials on site, process or reuse materials on-site (demolition and new construction).

## DOCUMENTATION

- To each application for progress payment submitted to the owner or its representative, the Contractor shall attach a record of the amount of material disposed (in tons) and the amount of each material recycled or salvaged by type (in tons or cubic yards, whichever is available). Manifests, weight ticket, receipts, and/or invoices can be used as documentation.
- The Contractor shall be responsible for providing such information whether directly involved in recycling the materials or not (whether the Contractor performs recycling tasks or hires or requires others, such as subcontractors, to do so).
- In the event the Contractor cannot fulfill the specified diversion rate for C&D waste generated by the project, the Contractor shall notify the Owner prior to submitting the final progress report. The Contractor must provide documentation showing a good faith effort was made to achieve the diversion rate. Such proof will include a record of contacts with C&D recycling businesses and shall include: date and time of contacts, name of business and contact, telephone, and results of contact.

## REFERENCES

- C&D Recycling Businesses: California Integrated Waste Management Board (CIWMB) lists C&D recyclers and processors (Pub #431-96-017) sorted by County (Pub#431-96-017). CIWMB also offers a searchable database of recyclers on its web site (http://www.ciwmb.ca.gov/ConDemo).
- Case Studies and Other Technical Assistance: See CIWMB website and links.

## SUBSTITUTIONS

Should the Contractor desire to use procedures, materials, equipment, or products that are not specified but meet the intent of these specifications to reduce materials waste, the Contractor shall propose these substitutions in accordance with Substitutions and "Or Equal" in General Requirements.

## REVENUES

Revenues or other savings obtained from recycled, reused, or salvaged materials shall accrue to Contractor unless otherwise noted in the Contract Documents.

## PRODUCTS

### MATERIALS

Recycled-content, salvaged, or otherwise resource-efficient products are specified in appropriate sections.

## EXECUTION

### DEMOLITION

See Section 02### for a list of items targeted for demolition. Plans identify specific items to be reused, salvaged, or left in place.

Recycle the items listed below (on or offsite).

- Concrete and asphalt
- Metals
- Wood
- Job-Shack wastes, including office paper, pop cans and bottles, and office cardboard.

Recycle other items as cost-effective. Possible additional items include: carpet and carpet pad.

### NEW CONSTRUCTION

Recycle the items listed below.

- Landclearing debris (rock and dirt)
- Concrete
- Asphalt
- Metals
- Wood
- Drywall
- Job-Shack wastes, including office paper, pop cans and bottles, and office cardboard.

Recycle other items as cost-effective. Possible additional items include: packaging

- Include in supply agreements a waste reduction provision specifying a preference for reduced, U-turn, and/or recyclable packaging.
- Use detailed take-offs and use to identify location and use in structure to reduce risk of unplanned and potentially wasteful cuts.
- Store materials properly to avoid wetting or other damage to materials as well as outdating. Materials that become wet or damp due to improper storage shall be replaced at contractor's expense.

Use safety meetings, signage, and subcontractor agreements to communicate the goals of the waste reduction plan. At a minimum, waste reduction goals will be discussed at the following meetings.

- Project Kick-Off Meeting

- Pre-Construction Meeting
- Regularly scheduled progress meetings (safety meetings).

Provide on-site instruction regarding appropriate separation, handling, recycling, salvage, reuse, and return methods to be used to achieve waste reduction goals.

Protect materials to be recycled from contamination. As part of regular clean-up, schedule visual inspections of dumpsters and recycling bins to identify potential contamination of materials.

END OF SECTION

# Section 01503 – Site Protection Plan

## GENERAL

### SUMMARY

Section Includes:

- Description of a Site Protection Plan
- Site Protection Requirements

Related Sections: Site protection specifications included in this section should be coordinated with the following sections of the Project Manual, including:

- Division 2: Site

Coordinate with related temporary controls, in particular:

- Section 015## - Stormwater management
- Section 01501 - Sustainable Job Site Operations – Waste Reduction
- Section 01502 - Sustainable Job Site Operations – Indoor Air Quality

## SITE PROTECTION

Goals: The owner has set the following site protection goals for jobsite operations on the project, within the limits of the construction schedule, contract sum, and available materials, equipment, products and services. The goals assume that all jurisdictional requirements are met as *a minimum* for stormwater management and erosion control. Goals include:

- Eliminate unnecessary site disturbance.
- Minimize impact on the site's natural (soil and water) functions.
- Eliminate water pollution and water quality degradation.

## SITE PROTECTION PLAN

Within fourteen (14) days after receipt of Notice of Award and prior to any waste removal by the Contractor from the Project, the Contractor shall develop and submit to the Owner for review a site protection plan. This plan shall be Part II of a "Sustainable Job Site Operations Plan."

The site protection plan shall include:

- Site protection materials list and documentation
- Maintenance/inspection schedule for site protection measures
- Construction vehicles protocol, including parking, project access, maintenance, and tire wash.

## REFERENCES

Reference best management practices in *EPA's Storm Water Management for Construction Activities*, Chapter 3 and relevant local jurisdiction publications.

## SUBSTITUTIONS

Should the Contractor desire to use procedures, materials, equipment, or products that are not specified but meet the intent of these specifications to protect the site, the Contractor shall propose these substitutions in accordance with Substitutions and "Or Equal" in General Requirements.

## PRODUCTS

### MATERIALS

- Least-toxic products for use on the site are specified in Division 2.

## EXECUTION

### ALL PHASES

- Conduct regular inspection and maintenance of site protection measures. Minimally, inspect all erosion and sedimentation measures after a heavy rainfall, defined as ½ inches in less than 24 hours.
- Provide redundant mechanisms for site protection of any critical or sensitive areas on site, as identified in Site Plan. Silt fencing fabric and other temporary site protection measures shall last for the life of the project.
- For oil and sediment separators, ensure detergent does not get into separator.
- Establish and post construction vehicles protocol for parking and access on the site. Provide a rocked heavy construction vehicle entrance and tire wash.
- Establish and post clean-up procedures for spills to prevent illicit discharges. To minimize risk, reduce hazardous wastes, including paints and other finish products, solvents, adhesives, and oils as follows:

Avoid overstocking

Adopt a first-in, first out policy

Label containers properly

Control access to storage areas and routinely inspect containers

Inspect all containers upon receipt. Reject leaking or damaged containers.

Coordinate topsoil preparation, planting, and maintenance using Integrated Pest Management (least toxic) protocol. Use least-toxic products for controlling pests and insects in detention ponds and for soil prep. Chemical weed eradication prohibited.

Use safety meetings, signage, and subcontractor agreements to communicate the goals of the site protection plan.

END OF SECTION

# Waste Reduction Plan

Project:____________________________________

## Waste Reduction Plan

### Salvaged Materials

| Materials | Estimated Quantities | Expected Condition | Hauler | Destination |
|---|---|---|---|---|
| | | | | |
| | | | | |
| | | | | |
| | | | | |
| | | | | |
| | | | | |
| | | | | |
| | | | | |

### Recycling

| Materials | Estimated Quantities | Expected Condition | Hauler | Destination |
|---|---|---|---|---|
| Concrete | | | | |
| Asphalt Rubble | | | | |
| Ferrous Metals | | | | |
| Non-Ferrous Metals | | | | |
| Wood | | | | |
| Cardboard | | | | |
| Other | | | | |
| | | | | |

Other Waste Reduction Actions Planned:

# APPENDIX B – CALCULATING COST-EFFECTIVENESS

## Introduction

Once you have identified initial costs and operating costs over the time horizon of the building, you must then decide if the proposed design is cost-effective. In some cases, you may want to consider more than one design alternative, in which case you will want to know which of the alternatives is the most cost-effective. This appendix provides the technical information you will need to make these assessments.

### Payback Period

The most common measure of economic performance is the payback period—the period of time it takes for the savings to equal the initial investment. Payback period is based on the construction cost difference between two competing lighting systems and the resulting savings due to the more efficient system. As a result, it can only be used to compare *two* competing alternatives. If multiple alternatives are to be evaluated, they must all be compared to a single base case.

While easy to understand, payback period is inadequate in comparing many design alternatives, in particular systems with different lives or maintenance costs. Consider for instance two options: one with a cost of $10,000 and annual savings of $2,000 per year and a second with a cost of $5,000 and annual savings of $1,000 per year. Both have a payback period of 5 years, but which is the better investment? The inadequacies of payback period are further exposed if the two retrofit options have different lives and varying maintenance or replacement costs. While the payback calculation can be adjusted to consider utility rebates and annualized maintenance costs, more detailed economic analysis based on net present value or internal rate of return is recommended.

### Cash Flow

### Net Present Value (Life-Cycle Cost)

Net present value is the sum of the initial costs and all future benefits and costs over the life of the building, discounted to present value. Benefits are generally assigned a positive value while costs are assigned a negative value. In comparing alternatives, the one with the highest net present value is the best investment. Net present value can be used to compare several different systems and is especially useful in comparing design alternatives with different or irregular cash flows, or design alternatives with different lives.

Expenses or costs that occur in the future have a smaller value in current dollars. The rate at which future expenses or costs are discounted is the *discount rate*. It is the percent reduction in future benefits or costs for each year in the future. An understanding of discount rate is necessary in order to understand other measures of economic performance such as net present value, annualized cost, benefit to cost ratio, or internal rate of return.

The discount rate can be "real" or "nominal." The real discount rate is the rate at which future benefits or costs are discounted without consideration for inflation. If future expenses and costs are quantified in current dollars, a real discount rate is used. It is generally easier to quantify future benefits and costs in current dollars, so a real discount rate is commonly used in economic analysis. If future expenses and costs are quantified in inflated dollars, then a nominal discount rate should be used. The nominal discount rate is the real discount rate plus the inflation rate.

The *discount rate* is the rate of return that an investor typically makes or expects to make from other investment opportunities with a similar risk. It also indicates whether an investor has a short-term or long-term perspective. Investors with a short-term perspective generally have a higher discount rate, while investors with a long-term perspective have a lower discount rate. Risk must also be considered in selecting a discount rate. Since investments in sustainable buildings involve little risk, the discount rate should be based on consideration of other low-risk investments such as government securities. Using this logic, if the return on investment for government securities is 8% and the general inflation rate is 5%, then an appropriate *real* discount rate is 3%.

A discount rate may be used to calculate the present value of future costs. The present value of a cost occurring "n" years in the future with a discount rate of "i" is obtained by multiplying the cost by a present worth factor. The present worth factor or PWF is given by the following equation:

$$PWF = \frac{1}{(1+i)^n}$$

Tables of present worth factors may be calculated for a variety of discount rates and years into the future so that the above equation does not have to be evaluated for every case. Such a table is included as Table A-1. To calculate the present worth of a future benefit or cost, select a value from the table based on the discount rate and the number of years into the future and multiply the selected value times the future cost or benefit. Keep in mind that if the future cost or benefit is quantified in today's dollars, a real discount rate should be used. Otherwise, a nominal discount rate should be used.

Energy costs or savings (like maintenance costs) also occur in the future and may need to be discounted to present value. The values in Table A-1 could be used to discount each annual energy cost, but there are easier ways. If a cost or benefit occurs as a time series, that is, the same cost or benefit occurs each year for some period of time, then the net present value of this series of costs or benefits can be determined by multiplying the first year cost times a series present worth factor (SPWF).

The SPWF for "n" years or periods and a discount rate of "i," can be calculated with the following equation.

$$SPWF = \frac{(1+i)^n - 1}{i(1+i)^n}$$

Table A-2 contains pre-calculated series present worth factors for a variety of discount rates and years into the future. To calculate the net present value of a time series of future benefits or costs, select a value from the table based on the discount rate and the number of years into the future and multiply the selected value times the first year cost or benefit.

### Benefit-to-Cost Ratio

Benefit-to-cost ratio is another way of evaluating investments. This is the ratio of the net present value of all benefits to the net present value of all costs. All investments with a ratio greater than one may be considered cost-effective. In comparing multiple investment alternatives, all would have to be compared to a base case. The one with the highest benefit-to-cost ratio is the best investment opportunity.

### Internal Rate of Return

The internal rate of return (IRR) is the discount rate at which the present value of future benefits in energy savings and maintenance cost savings is equal to the initial cost premium. Put another way, it is the return on investment with all future costs and savings considered. The IRR of an investment can be viewed as the amount of annual interest (in percent) paid on the investment over the life of the project. The internal rate of return must be calculated through a process of iteration, but many spreadsheet programs have built in functions that are capable of calculating the IRR.

### Annualized Cost

Annualized cost is a useful method of comparing lighting alternatives. The initial costs and periodic maintenance costs are converted to an equivalent annual payment and added to the annual energy costs. The design alternative with the lowest annual cost is the one that is most cost-effective. Annualized cost is especially useful when initial costs are financed. Like IRR, annualized cost can be calculated with spreadsheet programs.

## Other Issues

### Inflation and Energy Cost Escalation Rates

The price of all goods and services increases over time at the general inflation rate. As long as all future costs increase at the same rate, inflation may be ignored in evaluating the economic performance of investments in energy efficiency. With this approach, commonly used in economic analysis, all future costs are quantified in current dollars and discounted at a real discount rate.

If there is reason to believe that energy costs will increase at a rate different from the general inflation rate, each future energy cost should be quantified in inflated dollars and discounted to present value using a nominal discount rate.

## Tax Considerations

Investments in energy efficiency have tax implications that need to be considered in detailed economic analysis. Energy costs are an expense; so when energy costs are reduced, taxable income is increased and potentially some of the energy savings are paid to the government as additional taxes. On the other hand, investments in energy efficiency can be depreciated over the life of the equipment, offering a tax benefit. For many businesses, these offset each other, but they must be considered on a case-by-case basis.

### Table A-1 –Present Worth Factors

| | Discount Rate | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Number of Years | 1% | 2% | 3% | 4% | 5% | 6% | 7% | 8% | 10% | 12% | 14% | 16% | 18% |
| 1 | 0.99 | 0.98 | 0.97 | 0.96 | 0.95 | 0.94 | 0.93 | 0.93 | 0.91 | 0.89 | 0.88 | 0.86 | 0.85 |
| 2 | 0.98 | 0.96 | 0.94 | 0.92 | 0.91 | 0.89 | 0.87 | 0.86 | 0.83 | 0.80 | 0.77 | 0.74 | 0.72 |
| 3 | 0.97 | 0.94 | 0.92 | 0.89 | 0.86 | 0.84 | 0.82 | 0.79 | 0.75 | 0.71 | 0.67 | 0.64 | 0.61 |
| 4 | 0.96 | 0.92 | 0.89 | 0.85 | 0.82 | 0.79 | 0.76 | 0.74 | 0.68 | 0.64 | 0.59 | 0.55 | 0.52 |
| 5 | 0.95 | 0.91 | 0.86 | 0.82 | 0.78 | 0.75 | 0.71 | 0.68 | 0.62 | 0.57 | 0.52 | 0.48 | 0.44 |
| 6 | 0.94 | 0.89 | 0.84 | 0.79 | 0.75 | 0.70 | 0.67 | 0.63 | 0.56 | 0.51 | 0.46 | 0.41 | 0.37 |
| 7 | 0.93 | 0.87 | 0.81 | 0.76 | 0.71 | 0.67 | 0.62 | 0.58 | 0.51 | 0.45 | 0.40 | 0.35 | 0.31 |
| 8 | 0.92 | 0.85 | 0.79 | 0.73 | 0.68 | 0.63 | 0.58 | 0.54 | 0.47 | 0.40 | 0.35 | 0.31 | 0.27 |
| 9 | 0.91 | 0.84 | 0.77 | 0.70 | 0.64 | 0.59 | 0.54 | 0.50 | 0.42 | 0.36 | 0.31 | 0.26 | 0.23 |
| 10 | 0.91 | 0.82 | 0.74 | 0.68 | 0.61 | 0.56 | 0.51 | 0.46 | 0.39 | 0.32 | 0.27 | 0.23 | 0.19 |
| 11 | 0.90 | 0.80 | 0.72 | 0.65 | 0.58 | 0.53 | 0.48 | 0.43 | 0.35 | 0.29 | 0.24 | 0.20 | 0.16 |
| 12 | 0.89 | 0.79 | 0.70 | 0.62 | 0.56 | 0.50 | 0.44 | 0.40 | 0.32 | 0.26 | 0.21 | 0.17 | 0.14 |
| 13 | 0.88 | 0.77 | 0.68 | 0.60 | 0.53 | 0.47 | 0.41 | 0.37 | 0.29 | 0.23 | 0.18 | 0.15 | 0.12 |
| 14 | 0.87 | 0.76 | 0.66 | 0.58 | 0.51 | 0.44 | 0.39 | 0.34 | 0.26 | 0.20 | 0.16 | 0.13 | 0.10 |
| 15 | 0.86 | 0.74 | 0.64 | 0.56 | 0.48 | 0.42 | 0.36 | 0.32 | 0.24 | 0.18 | 0.14 | 0.11 | 0.08 |
| 16 | 0.85 | 0.73 | 0.62 | 0.53 | 0.46 | 0.39 | 0.34 | 0.29 | 0.22 | 0.16 | 0.12 | 0.09 | 0.07 |
| 17 | 0.84 | 0.71 | 0.61 | 0.51 | 0.44 | 0.37 | 0.32 | 0.27 | 0.20 | 0.15 | 0.11 | 0.08 | 0.06 |
| 18 | 0.84 | 0.70 | 0.59 | 0.49 | 0.42 | 0.35 | 0.30 | 0.25 | 0.18 | 0.13 | 0.09 | 0.07 | 0.05 |
| 19 | 0.83 | 0.69 | 0.57 | 0.47 | 0.40 | 0.33 | 0.28 | 0.23 | 0.16 | 0.12 | 0.08 | 0.06 | 0.04 |
| 20 | 0.82 | 0.67 | 0.55 | 0.46 | 0.38 | 0.31 | 0.26 | 0.21 | 0.15 | 0.10 | 0.07 | 0.05 | 0.04 |
| 21 | 0.81 | 0.66 | 0.54 | 0.44 | 0.36 | 0.29 | 0.24 | 0.20 | 0.14 | 0.09 | 0.06 | 0.04 | 0.03 |
| 22 | 0.80 | 0.65 | 0.52 | 0.42 | 0.34 | 0.28 | 0.23 | 0.18 | 0.12 | 0.08 | 0.06 | 0.04 | 0.03 |
| 23 | 0.80 | 0.63 | 0.51 | 0.41 | 0.33 | 0.26 | 0.21 | 0.17 | 0.11 | 0.07 | 0.05 | 0.03 | 0.02 |
| 24 | 0.79 | 0.62 | 0.49 | 0.39 | 0.31 | 0.25 | 0.20 | 0.16 | 0.10 | 0.07 | 0.04 | 0.03 | 0.02 |
| 25 | 0.78 | 0.61 | 0.48 | 0.38 | 0.30 | 0.23 | 0.18 | 0.15 | 0.09 | 0.06 | 0.04 | 0.02 | 0.02 |
| 26 | 0.77 | 0.60 | 0.46 | 0.36 | 0.28 | 0.22 | 0.17 | 0.14 | 0.08 | 0.05 | 0.03 | 0.02 | 0.01 |
| 27 | 0.76 | 0.59 | 0.45 | 0.35 | 0.27 | 0.21 | 0.16 | 0.13 | 0.08 | 0.05 | 0.03 | 0.02 | 0.01 |
| 28 | 0.76 | 0.57 | 0.44 | 0.33 | 0.26 | 0.20 | 0.15 | 0.12 | 0.07 | 0.04 | 0.03 | 0.02 | 0.01 |
| 29 | 0.75 | 0.56 | 0.42 | 0.32 | 0.24 | 0.18 | 0.14 | 0.11 | 0.06 | 0.04 | 0.02 | 0.01 | 0.01 |
| 30 | 0.74 | 0.55 | 0.41 | 0.31 | 0.23 | 0.17 | 0.13 | 0.10 | 0.06 | 0.03 | 0.02 | 0.01 | 0.01 |

### Table A-2 –Series Present Worth Factors

| | Discount Rate | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Number of Years | 1% | 2% | 3% | 4% | 5% | 6% | 7% | 8% | 10% | 12% | 14% | 16% | 18% |
| 1 | 0.99 | 0.98 | 0.97 | 0.96 | 0.95 | 0.94 | 0.93 | 0.93 | 0.91 | 0.89 | 0.88 | 0.86 | 0.85 |
| 2 | 1.97 | 1.94 | 1.91 | 1.89 | 1.86 | 1.83 | 1.81 | 1.78 | 1.74 | 1.69 | 1.65 | 1.61 | 1.57 |
| 3 | 2.94 | 2.88 | 2.83 | 2.78 | 2.72 | 2.67 | 2.62 | 2.58 | 2.49 | 2.40 | 2.32 | 2.25 | 2.17 |
| 4 | 3.90 | 3.81 | 3.72 | 3.63 | 3.55 | 3.47 | 3.39 | 3.31 | 3.17 | 3.04 | 2.91 | 2.80 | 2.69 |
| 5 | 4.85 | 4.71 | 4.58 | 4.45 | 4.33 | 4.21 | 4.10 | 3.99 | 3.79 | 3.60 | 3.43 | 3.27 | 3.13 |
| 6 | 5.80 | 5.60 | 5.42 | 5.24 | 5.08 | 4.92 | 4.77 | 4.62 | 4.36 | 4.11 | 3.89 | 3.68 | 3.50 |
| 7 | 6.73 | 6.47 | 6.23 | 6.00 | 5.79 | 5.58 | 5.39 | 5.21 | 4.87 | 4.56 | 4.29 | 4.04 | 3.81 |
| 8 | 7.65 | 7.33 | 7.02 | 6.73 | 6.46 | 6.21 | 5.97 | 5.75 | 5.33 | 4.97 | 4.64 | 4.34 | 4.08 |
| 9 | 8.57 | 8.16 | 7.79 | 7.44 | 7.11 | 6.80 | 6.52 | 6.25 | 5.76 | 5.33 | 4.95 | 4.61 | 4.30 |
| 10 | 9.47 | 8.98 | 8.53 | 8.11 | 7.72 | 7.36 | 7.02 | 6.71 | 6.14 | 5.65 | 5.22 | 4.83 | 4.49 |
| 11 | 10.37 | 9.79 | 9.25 | 8.76 | 8.31 | 7.89 | 7.50 | 7.14 | 6.50 | 5.94 | 5.45 | 5.03 | 4.66 |
| 12 | 11.26 | 10.58 | 9.95 | 9.39 | 8.86 | 8.38 | 7.94 | 7.54 | 6.81 | 6.19 | 5.66 | 5.20 | 4.79 |
| 13 | 12.13 | 11.35 | 10.63 | 9.99 | 9.39 | 8.85 | 8.36 | 7.90 | 7.10 | 6.42 | 5.84 | 5.34 | 4.91 |
| 14 | 13.00 | 12.11 | 11.30 | 10.56 | 9.90 | 9.29 | 8.75 | 8.24 | 7.37 | 6.63 | 6.00 | 5.47 | 5.01 |
| 15 | 13.87 | 12.85 | 11.94 | 11.12 | 10.38 | 9.71 | 9.11 | 8.56 | 7.61 | 6.81 | 6.14 | 5.58 | 5.09 |
| 16 | 14.72 | 13.58 | 12.56 | 11.65 | 10.84 | 10.11 | 9.45 | 8.85 | 7.82 | 6.97 | 6.27 | 5.67 | 5.16 |
| 17 | 15.56 | 14.29 | 13.17 | 12.17 | 11.27 | 10.48 | 9.76 | 9.12 | 8.02 | 7.12 | 6.37 | 5.75 | 5.22 |
| 18 | 16.40 | 14.99 | 13.75 | 12.66 | 11.69 | 10.83 | 10.06 | 9.37 | 8.20 | 7.25 | 6.47 | 5.82 | 5.27 |
| 19 | 17.23 | 15.68 | 14.32 | 13.13 | 12.09 | 11.16 | 10.34 | 9.60 | 8.36 | 7.37 | 6.55 | 5.88 | 5.32 |
| 20 | 18.05 | 16.35 | 14.88 | 13.59 | 12.46 | 11.47 | 10.59 | 9.82 | 8.51 | 7.47 | 6.62 | 5.93 | 5.35 |
| 21 | 18.86 | 17.01 | 15.42 | 14.03 | 12.82 | 11.76 | 10.84 | 10.02 | 8.65 | 7.56 | 6.69 | 5.97 | 5.38 |
| 22 | 19.66 | 17.66 | 15.94 | 14.45 | 13.16 | 12.04 | 11.06 | 10.20 | 8.77 | 7.64 | 6.74 | 6.01 | 5.41 |
| 23 | 20.46 | 18.29 | 16.44 | 14.86 | 13.49 | 12.30 | 11.27 | 10.37 | 8.88 | 7.72 | 6.79 | 6.04 | 5.43 |
| 24 | 21.24 | 18.91 | 16.94 | 15.25 | 13.80 | 12.55 | 11.47 | 10.53 | 8.98 | 7.78 | 6.84 | 6.07 | 5.45 |
| 25 | 22.02 | 19.52 | 17.41 | 15.62 | 14.09 | 12.78 | 11.65 | 10.67 | 9.08 | 7.84 | 6.87 | 6.10 | 5.47 |
| 26 | 22.80 | 20.12 | 17.88 | 15.98 | 14.38 | 13.00 | 11.83 | 10.81 | 9.16 | 7.90 | 6.91 | 6.12 | 5.48 |
| 27 | 23.56 | 20.71 | 18.33 | 16.33 | 14.64 | 13.21 | 11.99 | 10.94 | 9.24 | 7.94 | 6.94 | 6.14 | 5.49 |
| 28 | 24.32 | 21.28 | 18.76 | 16.66 | 14.90 | 13.41 | 12.14 | 11.05 | 9.31 | 7.98 | 6.96 | 6.15 | 5.50 |
| 29 | 25.07 | 21.84 | 19.19 | 16.98 | 15.14 | 13.59 | 12.28 | 11.16 | 9.37 | 8.02 | 6.98 | 6.17 | 5.51 |
| 30 | 25.81 | 22.40 | 19.60 | 17.29 | 15.37 | 13.76 | 12.41 | 11.26 | 9.43 | 8.06 | 7.00 | 6.18 | 5.52 |

# APPENDIX C – A FIELD-BASED THERMAL COMFORT STANDARD FOR NATURALLY VENTILATED BUILDINGS

Gail Schiller Brager, Ph.D. and Richard de Dear, Ph.D.

## Introduction

Architecture and engineering journals have been paying increasing attention to innovative non-residential buildings designed with operable windows. Such buildings may rely exclusively on natural ventilation for cooling, or may operate as mixed-mode, or "hybrid" buildings that integrate both natural and mechanical cooling. Architects who want to incorporate natural ventilation as an energy-efficient feature need to collaborate closely with mechanical engineers. Unfortunately, engineers often need to veto such natural approaches, citing their professional obligation to adhere to thermal comfort standards such as ASHRAE Standard 55 or ISO 7730. In their current form, these standards establish relatively tight limits on recommended indoor thermal environments, and do not distinguish between what would be considered thermally acceptable in buildings conditioned with natural ventilation vs. air-conditioning. In other words, engineers have not been given a suitable tool to help them decide when and where full HVAC is required in a building, and under what circumstances they can incorporate more energy-conserving strategies without sacrificing comfort.

ASHRAE Standard 55[1], "Thermal environmental conditions for human occupancy", was initially released in 1966. Since then, it has been revised once a decade, incorporating the latest technical advances in ofuur understanding of thermal comfort. Derived from laboratory experiments using a thermal-balance model of the human body, this standard has attempted to provide an objective criterion for thermal comfort — in particular, specifying combinations of personal and environmental factors that will produce interior thermal environments acceptable to at least 80% of a building's occupants. While ASHRAE Standard 55 was originally intended to provide guidelines for centrally-controlled HVAC, its broad application in practice is hindering innovative efforts to develop more person-centered strategies for climate control in naturally ventilated or mixed-mode buildings. Such strategies may hold great social and environmental benefits, reducing energy consumption and increasing occupant satisfaction, especially in office buildings.

Based on research funded by ASHRAE, this article argues that adequate scientific basis now exists to amend Standard 55 to include a more "adaptive" field-based alternative for application to naturally ventilated buildings. Such a proposal reflects findings that thermal preference in such buildings varies widely from predictions made by the present laboratory-based standard. The article suggests that one possible reason for this discrepancy may be that the heat-balance model of thermal comfort underlying the present standard cannot account for the complex ways people interact with their environments, modify their behaviors, or gradually adapt their expectations to match their surroundings.

## Adaptation In Buildings

Advocates for a more flexible thermal-comfort standard have long argued that the primary limitation of Standard 55 is its "one-size-fits-all" approach, where clothing and activity are the only modifications one can make to reflect seasonal differences in occupant requirements. The standard was originally developed through laboratory tests of perceived thermal comfort, with the limited intent to establish optimum HVAC levels for fully climate-controlled buildings. However, today, in the absence of any credible alternative, Standard 55 is being applied universally across all building types, climates and populations.

As a consequence, even in relatively mild climatic zones, it is hard to meet the standard's narrow definition of thermal comfort without mechanical systems. Many researchers and designers have argued, for example, that reliance on Standard 55 has allowed important cultural, social and contextual factors to be ignored, leading to an exaggeration of the "need" for air conditioning[2]. Others have argued that allowing people greater control of indoor environments, and allowing temperatures to more closely track patterns in the outdoor climate, could improve levels of occupant satisfaction with indoor environments and reduce energy consumption[3].

Such issues have particular relevance with regard to naturally ventilated buildings, where occupants are able to open windows, creating indoor conditions that are inherently more variable than buildings with centralized HVAC systems. In such settings, an alternative thermal comfort standard based on field measurements might be able to account for contextual and perceptual factors absent in the laboratory setting. Toward this end, the research began by focusing on three primary modes of adaptation: physiological, behavioral, and psychological.

Physiological adaptation, also known as acclimatization, refers to biological responses that result from prolonged exposure to characteristic and relatively extreme thermal conditions. One example in hot climates is a fall in the setpoint body temperature at which sweating is triggered, leading to an increased tolerance for warmer temperatures. Laboratory evidence suggests, however, that such acclimatization does not play much of a role in subjective preferences across the moderate range of activities and thermal conditions present in most buildings[4].

Behavioral adaptation refers to any conscious or unconscious action a person might make to alter their body's thermal balance[5]. Examples include changing clothes or activity levels, turning on a fan or heater, or adjusting a diffuser or thermostat. Behavioral adjustments offer the best opportunity for people to participate in maintaining their own thermal comfort. Affording ample opportunities for people to interact with and control the indoor climate is an essential strategy in the design of naturally ventilated buildings.

The psychological dimension of thermal adaptation refers to an altered perception of, and reaction to, physical conditions due to past experience and expectations. It is premised on the generalization, true across all sensory modalities (not just thermal), that that repeated exposure to a new stimulus leads to a diminution of the evoked response. It also includes the idea that a person's reaction to a temperature that is less than perfect will depend on expectations and on what that person is doing at the time[6].

## Research Methods

The research described in this paper involved assembling a quality-controlled database containing 21,000 sets of raw data compiled from previous thermal-comfort field experiments inside 160 different office buildings located on four continents and covering a broad spectrum of climatic zones[7]. The gender and age distribution of the subjects was typical of office building populations and the large size of the sample reduced the risk of bias that might occur in relatively smaller samples used in climate chamber experiments. The data included a full range of both subjective and physical measurements, including thermal questionnaire responses, clothing and metabolic estimates, concurrent indoor climate measurements, a variety of calculated thermal indices, and outdoor meteorological observations. Analysis of data was performed separately for buildings with centralized HVAC systems and naturally ventilated buildings (i.e., where occupants had access to operable windows). The analysis examined thermal comfort responses in terms of both thermal neutrality and preference, as functions of both indoor and outdoor temperatures. Observed responses were also compared to predictions of thermal sensation made using the heat-balance-based PMV model[8]. The PMV model is the basis for ISO Standard 7730[9], and for the next version of Standard 55.

The following sections present select aspects of the research that directly relate to the proposal for an "adaptive" thermal-comfort standard to be used as an alternate to PMV for naturally ventilated buildings in the next revision of ASHRAE Standard 55. A more detailed description of the research methods, statistical analysis techniques, and results can be found in ASHRAE Transactions papers[7,10].

## Thermal Comfort In Air-Conditioned Vs. Naturally Ventilated Buildings

### To what extent do people behaviorally adapt in the two building types?

Behavioral adaptation was analyzed by examining how changes in clothing, metabolic rate, and air velocity varied as functions of indoor temperature. Mean metabolic rates in both building types stayed fairly constant at about 1.2 met units regardless of indoor temperature, ranging within a fairly tight cluster of 1.1-14. met units. In contrast, changes in clothing and air velocity were both significantly related to changes in mean indoor operative temperatures in all buildings. The relationships were stronger, however, in the case of the naturally ventilated buildings. Mean clothing insulation values (including the incremental insulation of the chairs) varied seasonally in the HVAC vs. naturally-ventilated buildings, respectfully, from 0.70/0.66 clo in the summer, to 0.92/0.93 clo in the winter. Although the differences between the mean clothing values were not significantly different between the two building types, there was a much wider range of clothing worn in the naturally ventilated buildings, and a stronger relationship between clothing and indoor temperature. In the naturally ventilated buildings, mean thermal insulation decreased by an average of 0.1 clo units for every 2°C (3.6°F) increase in mean indoor temperature.

Air velocity is considered a form of behavioral adaptation when people are able to make the environmental adjustments themselves, such as opening or closing a window, turning on a local fan, or adjusting an air diffuser. Mean air speeds recorded in the HVAC buildings were generally confined to the region below 0.2 m/s (39.4 ft/min), as prescribed in ASHRAE Standard 55-1992. In naturally ventilated building, on the other hand, speeds above this limit were recorded when indoor temperatures extended beyond the upper temperature limit of 26°C (78.8°F) in ASHRAE Standard 55-1992. As will be shown below, however, these forms of behavioral adaptation could account for only part of people's acceptance of higher temperatures in the naturally ventilated buildings.

### How do people react as conditions deviate from the optimum?

A weighted linear regression model of the relationship between mean thermal sensation (TS) and mean indoor operative temperature ($T_{op}$) was used to judge how quickly people felt too warm or too cool as temperatures deviated from the optimum:

(centralized HVAC buildings) $TS = 0.51 * T_{op} - 11.96$ ($T_{op}$ in °C) (1)
$TS = 0.28 * T_{op} - 21.03$ ($T_{op}$ in °F)

(naturally ventilated buildings) $TS = 0.27 * T_{op} - 6.65$ ($T_{op}$ in °C) (2)
$TS = 0.15 * T_{op} - 11.45$ ($T_{op}$ in °F)

In these equations, TS represents a vote on the familiar ASHRAE 7-point thermal sensation scale, where TS=0 is "neutral". This analysis revealed that occupants of centralized HVAC buildings were twice as sensitive to such deviation as were occupants of naturally ventilated buildings. Such a finding suggests that people in air-conditioned buildings have higher expectations for thermal consistency, and quickly became critical if thermal conditions diverge from these expectations. In contrast, people in naturally ventilated buildings seem to demonstrate a preference for a wider range of thermal conditions, perhaps due to their ability to exert control over their environment, or because their expectations match the more variable conditions they are used to experiencing in such buildings.

### How does one define a "comfort temperature"? Does everyone always prefer to feel "neutral"?

The traditional method of defining a comfortable temperature is to assume that a "neutral thermal sensation" represents ideal conditions, and then solve a linear regression equation such as those given above for the "neutral temperature" at which TS=0. However, when surveys include a question about preference (usually expressed as "do you prefer to feel warmer, no change, or cooler?"), one can also calculate a "preferred temperature" in a similar way, assuming that a preference for "no change" represents ideal conditions.

Both types of analyses were conducted in the present project, with the result being that there was generally no difference in these measures for occupants of naturally ventilated buildings. However, in the HVAC buildings, the analysis revealed that people preferred slightly warmer-than-neutral temperatures in cold climates, and cooler-than-neutral temperatures in warmer climates (the difference being up to 1°C at either extreme end). Since we viewed "preference" as being a more appropriate indicator of optimum thermal conditions than the traditional assumption of "neutral thermal sensation," we developed a correction factor to modify calculations of neutral temperatures in HVAC buildings to more accurately reflect preference.

### Do indoor comfort temperatures change in relation to outdoor weather and climate?

Adaptive theory suggests that the thermal expectations of building occupants, and their subsequent expectations for indoor comfort, will be dependent on outdoor temperature. This relation may vary, however, based on the extent to which the indoor environment is connected to natural seasonal swings in outdoor climate. Figure 1 shows a regression of indoor comfort temperatures as defined above against an outdoor temperature index for centralized HVAC (left graph) and naturally ventilated (right graph) buildings. The outdoor temperature index used was mean effective temperature (ET*). Each graph shows the regressions based on both observed responses in the database and the PMV predictions.

Looking first at observed responses (dotted lines), the gradient for the naturally ventilated buildings was more than twice that found in buildings with centralized HVAC systems. One possible interpretation of this finding is that occupants of the HVAC buildings become more finely adapted to mechanically conditioned, static indoor climates. In comparison, the range in thermal comfort levels in naturally ventilated buildings showed a much larger variation, suggesting that occupants of these buildings preferred conditions that more closely reflected outdoor climate patterns.

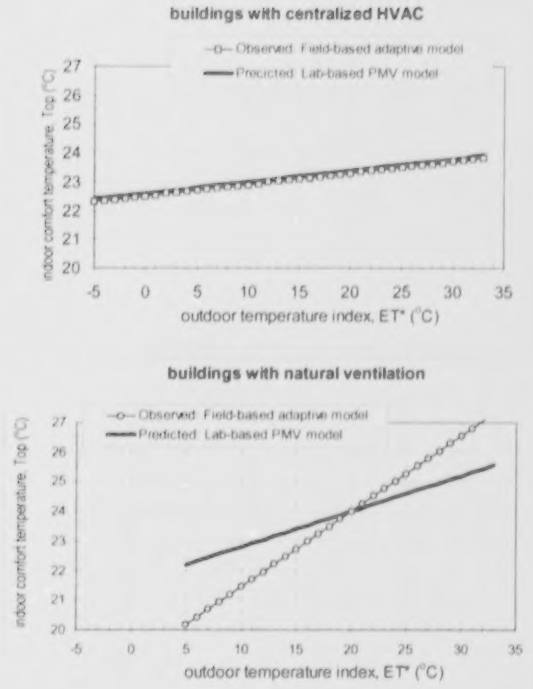

Figure 1. Observed and predicted comfort temperatures

### How do field-based measurements compare to lab-based predictions, and what does this say about adaptation?

Looking next at the observed and predicted lines within each graph in Figure 1 provides insight into how adaptation may influence the relationship between indoor comfort and outdoor climate in the two building types. Recall that clothing insulation and air velocity both had a statistical dependence on mean indoor temperatures (and are probably related to outdoor temperature as well). Both are included as inputs to the PMV model. Therefore, one would expect to see that the indoor comfort levels predicted by the PMV model might also show some dependence on outdoor climate. In fact, as seen in Figure 1, they do.

In the HVAC buildings (left-hand panel of Figure 1), the observed (dotted) and predicted (solid) lines appear very close together, demonstrating that PMV was remarkably successful at predicting comfort temperatures in these buildings. A corollary of this finding is that, in HVAC buildings, behavioral adjustments to clothing and room air speeds fully explain the relationship between indoor comfort temperature and outdoor climatic variation, and that these adaptive behaviors are, in fact, adequately accounted for by the PMV model.

However, the remarkable agreement between PMV and adaptive models in the HVAC buildings clearly breaks down in the context of naturally ventilated buildings (right-hand panel of Figure 1), where the observed responses show a gradient almost twice as steep as the PMV model's predicted comfort levels. By logical extension therefore, it appears that behavioral adjustments (clothing and air velocity changes) may account for only half of the climatic dependence of comfort temperatures within naturally ventilated buildings.

What explains the rest? Having accounted for the effects of behavioral adaptations, physiological (acclimatization) and psychological components of adaptation are left to explain the divergence. But, as noted previously, existing literature suggests that acclimatization is unlikely to be a significant factor. This leaves psychological adaptation as the most likely explanation for the difference between field observations and PMV predictions in naturally ventilated buildings. This means the physics governing a body's heat balance must be inadequate to fully explain the relationship between perceived thermal comfort in naturally ventilated buildings and exterior climatic conditions.

## An Adaptive Comfort Standard For Naturally Ventilated Buildings

Using Standard 55 to determine acceptable indoor temperature ranges requires one to know, or at least anticipate, the average metabolic rate and amount of clothing worn by people in a building, regardless of whether that building is already built or occupied. In contrast, an adaptive model relates acceptable indoor temperature ranges to mean monthly outdoor temperature (in this case, defined as the arithmetic average of mean monthly minimum and maximum air temperature). This is a parameter already familiar to engineers and can be easily found by examining readily available climate data, such as that published by the U.S. National Atmospheric and Oceanographic Administration (www.ncdc.noaa.gov). Because the adaptive model is based on extensive field measurements, the relationship between expected clothing and outdoor climate is already built into the empirical statistical relationship.

Although both laboratory and field studies typically collect subjective data in terms of thermal sensation, Standard 55 presents temperature limits in terms of acceptability (with the goal of achieving 80 percent acceptability in the field). To create the link between 80% acceptability and measured thermal sensation, we accepted one of the underlying assumptions of Fanger's PMV/PPD indices: namely, that a group mean thermal sensation (PMV) between the limits of ±0.85 corresponds with 20 percent of the group being dissatisfied (PPD). If one wanted to apply a more stringent level of acceptability to the adaptive model, or if one expected a building to present greater than normal thermal asymmetries, one might choose to use an acceptability criteria of 90 %, corresponding to a mean thermal sensation falling within the limits of ±0.5.

For comparison, it should be noted that the 80% acceptability comfort zone in Standard 55 is actually based on a 10% general dissatisfaction criteria for the body as a whole, corresponding to tests performed in the laboratory under uniform conditions. It then allows for an additional average of 10% dissatisfaction that might occur because of local thermal discomfort. Since the adaptive model is based on field measurements, where people are naturally integrating whole body plus local sensations, field votes already account for both sources of discomfort.

The adaptive model for naturally ventilated buildings is shown in Figure 2. To make it easier for engineers to use, the regressions in Figure 1 (originally using ET*) have been recalculated based on mean monthly outdoor air temperature. This comfort standard would be applicable to buildings in which occupants control operable windows, where there is no mechanical cooling, and where activity levels are < 1.2 met. As the outdoor temperature extends beyond the outdoor temperature limits that were included in the RP-884 database, the acceptable indoor temperature limits would remain constant at the maximum and minimum levels. To use this standard, engineers would simply calculate the average of the mean minimum and maximum air temperatures for a given month, and then use Figure 2 to determine the acceptable range of indoor operative temperatures for a naturally ventilated building. During the design phase of a building, these numbers could be compared to the output of a thermal simulation model of the proposed building to determine whether the predicted indoor temperatures are likely to be comfortable using natural ventilation, or if air-conditioning would be required. The figure could also be used to evaluate the acceptability of thermal conditions in an existing building by comparing the acceptable temperature range obtained from Figure 2 to indoor temperatures measured in the building.

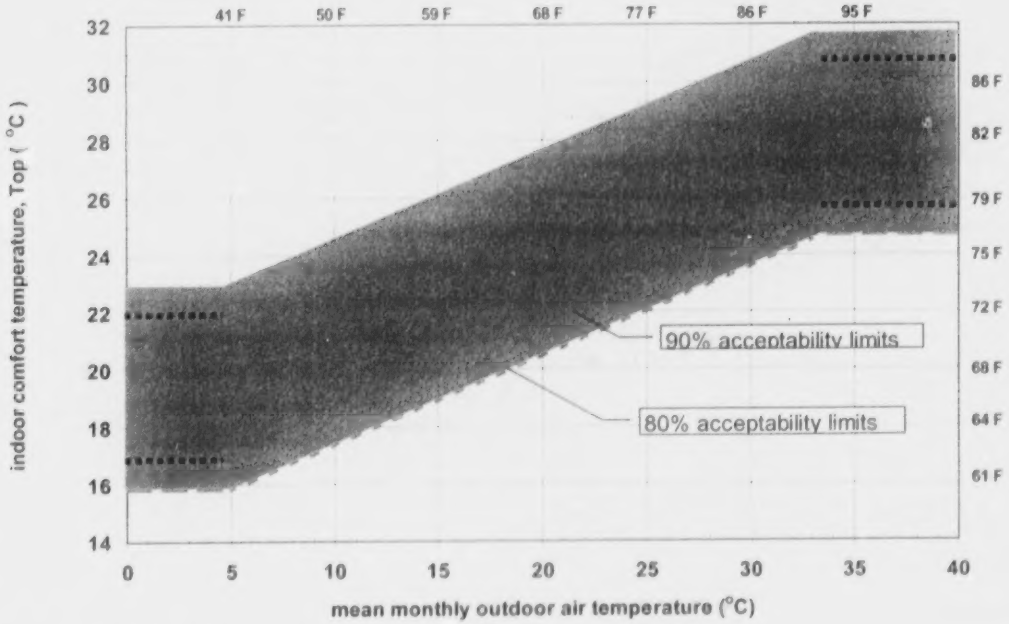

Figure 2. Proposed adaptive comfort standard for naturally ventilated buildings.

## Conclusions

The research has demonstrated that occupants of buildings with centralized HVAC systems become finely tuned to the very narrow range of indoor temperatures presented by current HVAC practice. They develop high expectations for homogeneity and cool temperatures, and soon became critical if thermal conditions do not match these expectations. In contrast, occupants of naturally ventilated buildings appear tolerant of – and, in fact, prefer – a wider range of temperatures. This range may extend well beyond the comfort zones published in ASHRAE Standard 55-92, and may more closely reflect the local patterns of outdoor climate change.

Further analysis of research findings established that behavioral adaptations, such as changes in clothing insulation or indoor air speeds, could account for only half the observed variance in thermal preferences of people in naturally ventilated buildings. Since it has been established that physiological adaptation is unlikely to play much of a role in relation to indoor office environments, this suggested the rest of the variance was attributable to psychological factors. Chief among these was a relaxation of thermal expectations possibly because of a combination of higher levels of perceived control and a greater diversity of thermal experiences in the building.

Such research suggests that accounting for these broader adaptive mechanisms allows mechanical engineers to design and operate buildings in ways that both optimize thermal comfort and reduce energy use. In many climatic settings, the practice of maintaining a narrowly defined, constant range of temperatures in fully air-conditioned buildings is unnecessary, and carries a very high energy cost. Unfortunately, the thermal comfort standards embodied in Standard 55 do not present alternative approaches to building conditioning. One reason is that the heat-balance models, on which the standard is based, were developed in tightly controlled laboratory conditions. In this process, people were considered passive subjects of climate change in artificial settings, and little consideration was given to the broad ways they might naturally adapt to a more wide-ranging thermal environments in realistic settings.

Along these lines, it may be noted that the laboratory context in which Standard 55 was established is quite similar to that of buildings with fully centralized HVAC systems. In fact, there is a historical connection between the two, since the standard was originally intended for application by the HVAC industry to the creation of "artificial climates" in "controlled spaces" (Fanger 1970). It is therefore not surprising that this research demonstrated that the PMV model could accurately predict people's patterns of thermal preference in fully air-conditioned buildings. However, the research showed that the PMV model could not predict people's thermal preferences in naturally ventilated buildings. This would seem to indicate the PMV model is an unsuitable guide when deciding whether or not to install HVAC systems in a particular building.

On the strength of this research we argue that an adaptive model of thermal comfort may usefully augment laboratory-based predictive models in the setting of thermal comfort standards. Furthermore, it would appear that such an approach is essential in order to account for additional contextual factors and individual experiences that appear to modify people's expectations in naturally ventilated buildings. As part of the next round of revisions to ASHRAE Standard 55, adoption of an alternative "adaptive" standard for naturally ventilated buildings may serve as a practical first step towards allowing engineers to adopt a more complex, socially and environmentally-responsive approach to evaluating and designing indoor climates. It would reflect growing awareness among researchers that factors beyond the mere passive experience of a body's thermal balance may play a significant role in determining human thermal preferences.

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# APPENDIX D – ENERGY COST AND IAQ PERFORMANCE OF VENTILATION SYSTEMS AND CONTROLS

**Indoor Environments Division**
**Office of Radiation and Indoor Air**
**Office of Air and Radiation**
**United States Environmental Protection Agency**
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**April, 1999**

## Executive Summary

Table 1 – Relationship Between Goals and Technical Chapters 4
Table 2 – Choosing an Appropriate Daylighting Strategy 14
Table 3 – Solar Optic Properties of Glazing Materials 15
Table 4 – Daylighting Analysis Tools 17
Table 5 – Recommended Daylighting Aperture – Sawtooth Roofs 23
Table 6 – HVAC Selection Criteria 30
Exhibit 1: Characteristics of the Base Buildings Modeled in this Study 16
Exhibit 3: Comparison of Outdoor Air Flows {design = 20 cfm (9 L/s) per person} for a Large Office Building with Alternative HVAC Systems 17
Exhibit 5: Comparison of Zone Level Outdoor Air Flow Rates {design = 20 cfm (9 L/s) per person} for Three Types of HVAC Systems in Office Buildings in Washington, DC. 18
Exhibit 6: Comparison of Annual Energy Costs for the Base Office Building with Alternative HVAC Systems and in Different Climates 19
Exhibit 8: Annual HVAC Energy Costs of Increasing Outdoor Air from 5 to 20 cfm per person for VAV(COA) Systems with Economizers 20
Exhibit 9: Impacts of Increased Outdoor Air Flows on Peak HVAC Coil Loads for VAV(COA) Systems with Economizers 21
Exhibit 10: Energy Measures that are Compatible with IEQ 22
Exhibit 11: Energy Measures that May Degrade IEQ 22
Exhibit 12: Modeling Parameters for the Office and Education Building 23
Exhibit 13: Energy Cost for Office Building with Energy and IEQ Modifications 24
Exhibit 14: Energy Cost for the Education Building with Energy and IEQ Modifications 24
Exhibit 15: Percent Savings in Total Energy Cost from Energy and IEQ Modifications 24
Exhibit 16: Energy Costs of Operational Measures that May Have Adverse Effects on IEQ 25
Exhibit 17: Savings from Reduced Lights and Office Equipment when Unoccupied25

## Purpose And Scope of this Report

In it's 1989 Report to Congress on Indoor Air Quality, the United States Environmental Protection Agency provided a preliminary assessment of the nature and magnitude of indoor air quality problems in the United States, the economic costs associated with indoor air pollution, and the types of controls and policies which can be used to improve the air quality in the nation's building stock. In that report, EPA estimated that the economic losses to the nation due to indoor air pollution was in the "tens of billions" of dollars per year, and suggested that because of the relative magnitude of operating costs, labor costs, and rental revenue in most buildings, it is possible that modest investments toward improved indoor air quality would generate substantial returns. Since that time, EPA has attempted to further define the costs and benefits to the building industry of instituting indoor air quality controls.

This project - *Energy Cost and IAQ Performance of Ventilation Systems and Controls* - is part of that effort. Adequate ventilation is a critical component of design and management practices needed for good indoor air quality. Yet, the energy required to run the ventilation system constitutes about half of a building's energy cost. Since energy efficiency can reduce operating costs and because the burning of fossil fuels is a major source of greenhouse gases, energy efficiency has become an important concern to the building industry and the promotion of efficient energy utilization has become a matter of public policy. It is important, therefore, to examine the relationship between energy use and indoor air quality performance of ventilation systems.

This project represents a substantial modeling effort whose purpose is to assess the compatibilities and trade-offs between energy, indoor air quality, and thermal comfort objectives in the design and operation of HVAC systems in commercial buildings, and to shed light on potential strategies which can simultaneously achieve superior performance on each objective.

This project seeks to examine three related fundamental questions:

- How much seasonal and spatial variation in IAQ performance may be expected from commonly used HVAC systems and controls and what are the IAQ implications of these variations?
- What is the energy cost associated with meeting ASHRAE indoor air quality performance standards for HVAC systems?
- How much energy reduction would have to be sacrificed in order to maintain minimum indoor air quality performance of HVAC systems in the course of energy efficiency projects?

The indoor air performance standards for HVAC systems used in this project are indoor air quality flow rates contained in ANSI/ASHRAE Standard 62-1989, *Ventilation for Acceptable Indoor Air Quality*, and temperature and relative humidity requirements for thermal comfort based on ANSI/ASHRAE Standard 55-1992, *Thermal Environmental Conditions for Human Occupancy*. The outdoor air flow rate criteria used were 20 cfm per occupant for office spaces, and 15 cfm per occupant for educational buildings and auditoriums as per ANSI/ASHRAE Standard 62-1989[2]. The thermal comfort criteria in ANSI/ASHRAE Standard 55-1992 were considered satisfied if space temperatures were maintained at 70$^0$ F - 79$^0$ F and relative humidity levels were maintained between 20% and 60%[3]. When judging HVAC performance, these criteria were used to set the outdoor air controls and space temperature set points. The actual outdoor air flows, space temperatures, and space relative humidity were then compared with these criteria to judge the performance of the system. Where appropriate, operational changes were undertaken to insure that the criteria were met and the associated changes in energy cost were examined.

While indoor air quality can arguably be controlled by different combinations of source control, ventilation control, and/or air cleaning technologies, no attempt was made in this project to study the potential for maintaining acceptable indoor air quality at reduced ventilation rates through the application of source control and air cleaning methods. In addition, while the impact of polluted outdoor air on the indoor environment is noted in discussions of outdoor air flow rates, no attempt was made to assess the implications of treating the outdoor air prior to entry into the building. In general, this project attempted to examine issues facing HVAC design and operational engineers during the most common applications of the indoor air quality and thermal comfort standards as prescribed by ASHRAE.

In addition, since outdoor air flow rates of 5 cfm per occupant were allowed by ASHRAE Standard 62-1981, energy costs for both 5 cfm per occupant (which were commonly used prior to 1989) as well as the above referenced 15 and 20 cfm per occupant, were estimated in order to determine the cost implications of raising the outdoor air flow rates from the previously allowed to the current ASHRAE outdoor air requirements.

It is hoped that this project will contribute to the body of new data needed by professionals and practitioners who design and operate ventilation systems as they attempt to reduce costs and save energy without sacrificing thermal comfort or outdoor air flow performance. This information should also assist in the development of public policies and strategies directed toward improvements in building performance as it relates to public health, productivity, and the conservation of energy resources.

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[2] The outdoor air flow rates specified in ASHRAE 62-1989 are designed to dilute indoor generated contaminants to acceptable levels where no significant indoor sources of pollution are present, and where the outdoor air quality meets applicable pollution standards. Thus, where significant indoor sources of pollution are present, these would have to be controlled. In addition, unacceptable concentrations of contaminants in the outdoor air would have to be removed prior to its entering occupied spaces. These issues were not specifically addressed in this modeling project.

[3] ASHRAE Standard 55-1992 describes several factors which affect thermal comfort, including air temperature, radiant temperature, humidity, air speed, temperature cycling and uniformity of temperature, when establishing criteria for thermal comfort. The modeling in this project addresses only the air temperature and relative humidity factors.

# Methodology

The process of investigating indoor air quality (IAQ) and energy use can be time-consuming and expensive. In order to streamline the process, this study employed a building simulation computer modeling procedure. The computer modeling approach enabled the investigation of multiple variations of building configurations and climate variations at a scale which would not otherwise be possible with field study investigations.

The methodology used in this project has been to refine and adapt the DOE-2.1E building energy analysis computer program for the specific needs of this study, and to generate a detailed database on the energy use, indoor climate, and outdoor air flow rates of various buildings, ventilation systems and outdoor air control strategies.

## Buildings and Climate

One large office building, an education building, and an auditorium formed the basis for most of this study. Summary characteristics of these buildings are presented in Exhibit 1. In addition, however, thirteen variations of the office building were used to examine how these variations impacted the energy costs of increasing outdoor air flow rates from 5 to 20 cfm per occupant, while slight modifications to the education building were made to examine the combined application of energy efficiency and indoor air quality controls.

Each building was modeled with (1) a dual duct constant volume (CV) system with temperature reset; and (2) a single duct variable volume (VAV) system with reheat. Outdoor air controls include a fixed outdoor air fraction (FOAF), and constant outdoor air (COA) flow. The FOAF strategy maintains a constant outdoor air fraction (percent outdoor air) irrespective of the supply air volume. For VAV systems, the FOAF could potentially be approximated in field applications by an outdoor damper in a fixed position (Cohen 1994; Janu 1995; and Solberg 1990), but specific field applications are not addressed in this study. The FOAF strategy was modeled so that the design outdoor air flow rate is met at the design cooling load, and diminishes in proportion to the supply flow during part-load. The COA strategy maintains a constant volume of outdoor air irrespective of the supply air volume. In a CV system, the FOAF and the COA strategies are equivalent, and are referred to in this report as CV (FOAF). In a VAV system, the COA strategy might be represented in field applications by a modulating outdoor air damper which opens wider as the supply air volume is decreased in response to reduced thermal demands. Specific control mechanics which would achieve a VAV (COA) have been addressed by other authors, (Haines 1986, Levenhagen 1992, Solberg 1990) but are not addressed in this modeling project.

In this study two types of air-side economizer strategies were also modeled: one controlled by outdoor air temperature ($ECON_T$) and one controlled by outdoor air enthalpy ($ECON_E$). The economizer is designed to override the minimum outdoor air flow called for by the prevailing strategy (FOAF or the COA) by bringing in additional quantities of outdoor air to provide "free cooling" when the outdoor air temperature (or enthalpy) is lower than the return air temperature (or enthalpy). In addition, the temperature economizer is prevented from operating when outdoor air temperatures exceed 65°F in order to avoid potential humidity problems. While the enthalpy economizer was modeled for comparison purposes, the temperature economizer was the primary economizer control used in various parts of this study.

### Climates and Utility Rates

Each building was modeled using TMY formatted weather data for three different cities, each representing distinctly different climate regions: Minneapolis, MN (cold climate regions), Washington, DC (temperate climate regions), and Miami, FL (hot and humid climate regions). Five different utility rate structure were modeled to determine the extent to which energy cost impacts from various parametric changes were dependent on utility rate structures. The base utility rate structure represents the average of prices taken from utilities in 17 major cities around the country in 1994. The price of electricity was modeled at $0.05 per kilowatt-hour, and $8 per kilowatt. Gas for space heating and DHW service was modeled at $0.50 per therm. The sensitivity of the results in this study to alternative utility rate structures was also tested.

## Limitations

Any analysis, however thorough, is inevitably constrained by the state of the art and resource available. Several fundamental limitations to the analysis in this project must be recognized.

- The analysis is ultimately constrained by the extent to which the model used accurately reflects real world performance.
- While a large number of building and ventilation parameters were used, they are limited in comparison to the many and varied building and ventilation characteristics in the nation's building stock. While the parameters were chosen to capture important variations, they are not necessarily representative.
- The model assumes that all equipment functions as it was intended to function. Faulty design, improper installation, and malfunctioning equipment due to poor maintenance, which are not uncommon in existing buildings, were not modeled.

## Issues Addressed in the Project

Seven reports, covering the following questions describe the issues addressed in this project:

**Project Report #1: Project Objectives and Methodology**

- What is the purpose of the project?
- What modeling tool was used and what modifications were made to meet the needs of this project?

- What buildings, HVAC systems, outdoor air control strategies, and utility rate structures were used, and how were they combined in simulations which constitute the database for this project?

**Project Report #2: Assessment of CV and VAV Ventilation Systems and Outdoor Air Control Strategies for Large Office Buildings-- Outdoor Air Flow Rates and Energy Use**

- Are there significant differences in outdoor air flow and energy cost among different HVAC systems and outdoor air control strategies?
- What HVAC system/outdoor air control strategy combinations offer the best and the worst results?
- What are the trade-offs and compatibilities between energy cost and outdoor air performance among the combinations studied?

**Project Report #3: Assessment of CV and VAV Ventilation Systems and Outdoor Air Control Strategies for Large Office Buildings-- Zonal Distribution of Outdoor Air and Thermal Comfort Control**

- How well do HVAC systems and outdoor air control strategies deliver design quantities of outdoor air to individual zones?
- Can shortfalls in particular zones be easily corrected and at what energy cost?

**Project Report #4: Energy Impacts of Increasing Outdoor Air Flow Rates from 5 to 20 cfm per Occupant in Large Office Buildings**

- What are the energy costs of raising outdoor air flow rates from 5 to 20 cfm per occupant for office buildings?
- How does the cost impact vary among different ventilation systems, outdoor air control strategies, and climates?

**Project Report #5: Peak Load Impacts of Increasing Outdoor Air Flow Rates from 5 to 20 cfm per Occupant in Large Office Buildings**

- Do HVAC system capacity problems result when outdoor air flow rates are raised in existing buildings (designed for 5 cfm of outdoor air per occupant) to conform with ASHRAE 62-1989?
- How significant are such problems and when are they most likely to occur?
- What implications do peak load impacts have on desires to downsize equipment in order to reduce first costs and save energy?

**Project Report #6: Potential Problems in IAQ and Energy Performance of HVAC Systems When Outdoor Air Flow Rates Are Increased from 5 to 15 cfm per Occupant in Education Buildings, Auditoriums, and Other Very High Occupant Density Buildings**

- What operational difficulties are presented by the requirement for large quantities of outdoor air for schools, auditoriums and other buildings with high occupant densities and how can these difficulties best be solved?
- What are the energy costs of increasing outdoor air flow from 5 to 15 cfm per occupant as per ASHRAE Standard 62-1989 for schools, auditoriums, and other buildings with high occupant densities, and how much can these costs be mitigated?

**Project Report #7: The Impact of Energy Efficiency Strategies on Energy Use, Thermal Comfort, and Outdoor Air Flow Rates in Commercial Buildings**

- What energy efficiency measures are compatible and what measures are incompatible with indoor environmental quality?

- What are the energy savings and penalties associated with measures to protect the indoor environments during energy efficiency projects?
- What protections and enhancements to indoor environmental quality can reasonably be employed in energy management and retrofit projects without sacrificing energy efficiency?

## Key Results

- **VAV Systems Save Energy:** Variable air volume systems provided $0.10 - $0.20 energy savings per square foot over constant volume systems.
- **VAV with Fixed Outdoor Air Fractions Caused Outdoor Air Flow Problems**: VAV systems may require a different outdoor air control strategy at the air handler to maintain adequate outside air for indoor air quality than the constant volume predecessor. If the fixed outdoor damper strategy of the CV system, which is commonly used in the VAV systems, results in a fixed outdoor air fraction, the outdoor air delivery rate at the air handler will be cut to about one half to two thirds the design level during most of the year.
- **Core Zones Received Significantly Less Air than Perimeter Zones and space temperatures tended to be higher:** Both CV and VAV systems provided an unequal distribution of supply air and outdoor air to zones. The south zone received the highest and the core zone received the least outdoor air. The core zone received only about two thirds of the building average outdoor air flow and had higher space temperatures.
- **Core Zones in VAV Systems with a Fixed Outdoor Air Fraction Received Very Little Outdoor Air**: The VAV system with fixed outdoor air fraction diminished the outdoor air delivery to the core zone to only about one third of the design level. With a design level of 20 cfm of outdoor air pe occupant, the core zone received only 6-8 cfm per occupant, and only 2-3 cfm per occupant with a design level of 5 cfm per occupant. Along with higher temperatures in the core zone, this shortfall could contribute to higher indoor air quality complaint rates in the core relative to the perimeter zones.
- **VAV with Constant Outdoor Air Control Displayed Improved Indoor Air Performance without any Meaningful Energy Penalty.** A VAV system with an outdoor air control strategy that maintains the design outdoor air flow at the air handler all year round had slightly lower energy cost in the cold climate, and slightly more energy cost in the hot and humid climate. It is therefore comparable in energy cost, but preferred for indoor air quality.
- **Economizers on VAV Systems May Be Advantageous for Both Indoor Air Quality and Energy in Cold and Temperate Climates.** By increasing the outdoor air flow when the outside air temperature (or enthalpy) is less than the return air temperature(or enthalpy), economizers can reduce cooling energy costs. For office buildings, economizers may operate to provide free cooling even at winter temperatures (e.g. at zero degrees Fahrenheit), provided that coils are sufficiently protected from freezing. For the office building, energy savings of about $0.05 per square foot were experienced by the VAV system economizer over the non-economizer VAV system in cold and temperate climates. The economizer on the CV system was much less advantageous due to increases in heating energy costs for this system, and was actually more expensive under some utility rate structures. The need to control or relative humidity and the potential introduction of outdoor contaminants are potential disadvantages of economizer systems.

- **VAV with Constant Outdoor Air Control and an Economizer Offers Significant Advantages, while VAV with Fixed Outdoor Air Fraction and No Economizer offers offers Significant Disadvantages:** Of all the ventilation systems and controls studied, the VAV system with constant outdoor air flow, which in cold and temperate climates is combined with an economizer and proper freeze control and humidity control, provided the good overall performance considering outdoor air flow, thermal comfort and energy efficiency. The VAV system with a fixed outdoor air fraction and no economizer provided the poor overall performance because it failed to deliver adequate outdoor air and had no energy benefit.
- **Raising Outdoor Air to Meet ASHRAE Standard 62-1989 in Office Buildings Resulted in Very Modest Increases in Energy Costs.** Raising outdoor air flow from 5-20 cfm per occupant in office buildings typically raised HVAC energy costs by only \$0.02 - \$0.08 per square foot (2% - 10%) depending type of system and climate. Considering the total energy bill, this increase amounted to approximately 1% - 4%. This is much less than is commonly perceived by practitioners. The cooling cost increases in the summer months were counterbalanced by cooling cost savings during cooler weather. Cost increases were higher for economizer systems than systems without economizers because much of the cost savings from higher outdoor air flow rates during cooler weather was already captured by the economizer system. The most significant factor affecting this increase was occupant density.
- **VAV Systems in Education, Auditoriums, and Other Buildings with Very High Occupant Densities May Require Special Adjustments for Meeting the High Outdoor Air Flow Rates of ASHRAE 62-1989.** In the education and auditorium buildings, the higher per occupant outdoor air requirements sometimes exceeded the total supply air needed to control thermal comfort. Even with the constant outdoor air damper control on the VAV system, the VAV box minimum settings had to be raised to what appear to be uncommonly high levels (e.g. 50% - 100% of peak flow), in order to maintain 15 cfm per occupant during part load.
- **Controlling Humidity Can be a Problem for Education Buildings, Auditoriums or Other Buildings with Very High Occupant Densities where HVAC Systems Must Deliver High Outdoor Air Flows to Meet ASHRAE Standard 62-1989.** Relative humidity frequently exceeded 60% and occasionally exceeded 70% in all climates in the education buildings and the auditoriums even though the cooling coils were adequately sized to handle peak loads and the indoor temperatures were well controlled. Problems occurred at part load during mild weather when the outdoor relative humidity was high. The increased dominance of the outdoor air at 15 cfm per occupant meant that the heating and cooling system had to deal with wide ranges in the sensible to latent heat ratio, so that humidity as well as temperature had to be part of the control regime. Controlling humidity may be a subject of special concern in buildings with very high occupant densities which meet the outdoor air flow requirements of ASHRAE Standard 62-1989.
- **The Outdoor Air Requirements of ASHRAE Standard 62-1989 for Education Buildings, Auditoriums and Other Buildings with Very High Occupant Densities Can Create a Significant Energy Burden.** When outdoor air ventilation rates were raised from 5 to 15 cfm per occupant in the education building and the auditorium, and when all adjustments were made to insure adequate outdoor air flow rates at part load, and relative humidity was controlled to 60% or below, HVAC energy costs rose by \$0.13 -\$0.27 per square foot (15%-32%) in the education building, and by \$0.36 -\$0.88 per square foot (26% - 67%) in the auditorium. This was judged to be a significant energy burden.

- **Contrary to Conventional Wisdom, the Impact of Raising Outdoor Air Flow Rates in High Occupant Density Buildings may be Least in Hot Humid Climates.** While raising outdoor air flow rates in the education and auditorium buildings raised cooling costs in Miami more than it did in Minneapolis and Washington, D.C., this was more than offset by the high increase in heating and fan energy these climates which was not experienced in Miami. The net result was much less relative impact in Miami.
- **Peak Loads, and therefore Equipment Capacity Requirements, may be Significantly Impacted when Outdoor Air Ventilation Rates are Raised.** Raising the rate from 5 to 20 cfm per occupant in office buildings often raised peak coil requirements by 15% - 25%, and created preheat requirements where none had previously existed. Raising the outdoor air flow rate from 5 to 15 cfm increased the peak loads by 25%-35% in the education building, and by 35% - 40% in the auditorium. This could provide real limits to downsizing strategies which are often part of an energy efficiency strategy, and calls for specific steps to reduce peak loads without sacrificing outdoor air requirements. It also suggests indoor air consultants advise clients of existing buildings to raise outdoor air flow rates in order to reduce indoor air quality complaints, should first consider the potential need to either increase capacity or reduce peak loads. Buildings without sufficient capacity may find themselves unable to maintain thermal comfort in the face of these higher outdoor ventilation rates, or in the worst scenario, may experience coil damage.
- **Energy Recovery Technologies May Potentially Reduce or Eliminate the Humidity Control, Energy Cost and Sizing Problems Associated with ASHRAE Standard 62-1989 in Education Buildings, Auditoriums, and Other Buildings with Very High Occupant Density.** While DOE-2 has limited capabilities to adequately model energy recovery technologies, some literature suggests that both latent and sensible energy recovery systems may significantly reduce or eliminate the associated problems of controlling thermal comfort, reducing energy costs, and downsizing equipment needs while meeting the outdoor air requirements of ASHRAE Standard 62-1989 in high occupant density buildings. Corroborating research could be of great value.
- **Protecting or Improving Indoor Environmental Quality During Energy Efficiency Projects May Not Hamper Energy Reduction Goals.** Many energy efficiency measures with the potential to degrade indoor environmental quality appear to require only minor adjustments to protect the indoor environment. When energy efficiency retrofit measures (including lighting upgrades), which were adjusted to either enhance or not degrade indoor environmental quality, were combined with measures to meet the outdoor air requirements of ASHRAE Standard 62-1989, total energy costs were cut by 35% - 45%. Operational measures compatible with indoor environmental quality cut total energy costs by 10%-20%. Avoiding operational measures that degrade indoor environmental quality meant that total energy reductions of only 3%-5% in the office building, and 7%-10% in the education building were foregone. There appears to be demonstrable compatibility between indoor environmental goals and energy efficiency goals, when energy saving measures and retrofits are applied wisely.

## Discussion

### Relative Performance of Alternative HVAC Systems and Outdoor Air Control Strategies

Exhibit 2 presents the outdoor air flow rate by outdoor air temperature for CV and VAV systems. The design outdoor air flow for each system was set at 20 cfm per occupant. The CV(FOAF) and the VAV(COA) configurations provided 20 cfm of outdoor air per occupant at all times and in all climates. However, the VAV(FOAF) system never provided 20 cfm of outdoor air per person -- except on the design day -- because as the supply air flow rate is throttled back from design conditions, the outdoor air flow into the building is reduced proportionally, to between one third to two thirds the design flow rate most of the time.

Exhibit 3 presents the proportion of occupied hours that each HVAC system in the base office building experiences an outdoor air flow within designated ranges. The outdoor air performance of the VAV(FOAF) systems varied with climate location. The system's outdoor air performance was best in the hot Miami climate, and worst in the cold Minnesota climate. This is because a larger portion of the year is spent at low cooling load conditions in Minneapolis relative to Washington D.C. and Miami. An economizer significantly improved the outdoor air performance of the VAV(FOAF) system for Minneapolis and Washington D.C., but only when the economizer was operational. As expected, the economizer made little difference in the outdoor air performance in the Miami climate.

Variations in outside air distribution due to variations in the thermal loads on the base office building[4] with VAV(COA) in Washington, D.C. are shown in Exhibit 4. For the VAV(COA) system, the outdoor air flow at the air handler is consistently at the design level of 20 cfm (9.2 L/s) per occupant, but there is wide divergence in the outdoor air flow rate to the zones, with the divergence depending on the outdoor temperature. At all temperatures, the core zone is being consistently under ventilated relative to the building design flow rate and receives the least outdoor air during hot weather, when a large portion of the supply air flows to the south zone because of its high cooling load. The zonal pattern would be similar for the VAV(FOAF) system, except that the outdoor air flow rate for each zone is lower, corresponding to the reduced air flow into the building described above.

Since the ventilation disparity between zones is seasonal, the extent to which each zone is over ventilated or under ventilated over the course of the year depends in part on the proportion of occupied hours the building is experiencing various outdoor air temperatures. Exhibit 5 presents the proportion of occupied hours that each zone experiences various outdoor air ventilation rates for different ventilation systems. This table shows that for a design outdoor air flow rate of 20 cfm (9 L/s) per occupant, the core zone of the CV(FOAF) system consistently receives 11-15 cfm (5 - 7 L/s) per occupant, while the core zone for the VAV(COA) system receives this amount about half the time. However, a striking observation is that the core zone for the VAV(FOAF) system receives only 6 - 10 cfm (2 - 4 L/s) of outdoor air per occupant all year round. While not shown here, patterns for other climates are similar. Also, adjusting VAV box settings (not shown here) did not resolve this problem.

Operational modifications (not shown here) to improve the performance of the VAV(FOAF) system were also modeled. Raising the outdoor air setting at design to 30 cfm (14 L/s) per occupant in Miami was sufficient to achieve at least 15 cfm (7 L/s) per occupant year round, but raised HVAC energy costs by $.03 per square foot. For Minneapolis and Washington D.C., raising the design setting to 45 cfm (21 L/s) per occupant was necessary to achieve 15 cfm per occupant year round, raising HVAC energy costs by $ .05 - $.06 per square foot respectively. A seasonal reset strategy was also modeled with similar results. However, making operational adjustments such as these runs the risk of exceeding capacity during extreme weather conditions and may not be advisable.

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[4] The occupant density is the same for each zone.

Exhibit 6 shows the energy costs for the CV system and the VAV systems with and without economizers. Comparisons of the energy costs of the CV(FOAF) and the VAV(COA) demonstrates the energy advantage of the VAV system over its CV counterpart. Both systems provide 20 cfm (9 L/s) under all operating conditions, but the energy cost for the VAV system is $0.10 - $0.20 less than the CV system. Much of this is due to the reduction in fan energy costs.

It is also useful to compare the VAV(FOAF) with the VAV(COA). The VAV(FOAF) system consistently delivers less than 20 cfm (9 L/s) of outdoor air, but offers no energy advantage over the VAV(COA) system which delivers a constant 20 cfm (9 L/s) per occupant. That is, the diminished outdoor air flow of the VAV(FOAF) system does not reduce energy costs over the VAV (COA) system. In fact, for the cold and temperate climates of Minneapolis and Washington D.C., energy costs of the VAV(FOAF) system are marginally greater than the VAV(COA) system, and only marginally less than the VAV(COA) system in Miami. This result is consistent with the fact that additional outside air during cooler weather provides some degree of free cooling, which is the concept underlying the economizer outdoor air control strategy. The added cooling benefit of the additional outdoor air in the VAV(COA) system tends to offset the added cooling burden during the hot summer season. However, when economizers are added to both systems, both systems experience free cooling. Thus, the VAV(FOAF)Econ saves about $.02 per square foot over the VAV(COA)Econ.

Economizers reduce HVAC energy costs 6% - 10% on VAV systems compared to only 1% to 2% for CV systems. The economizer for the CV system provides significant savings in cooling energy for the core zone, but this is partially counterbalanced by a heating penalty for the perimeter zones. While the economizer brings in sufficient outdoor air to reduce the mixed air temperature to 55$^{O}$ F in both systems, the supply air quantity of the CV system is considerably higher than that of the VAV system, and this results in a substantial heating penalty for the CV system economizer. Since gas is used for space heating, the advantage of the CV economizer is sensitive to the price of gas relative to electricity. In fact, while not shown here, for pricing structures involving high gas and low electricity prices , the CV economizer raised rather than lowered energy costs. As expected, economizers have a meaningful impact on energy costs only in cold and temperate climates. Because the Miami climate offers little opportunity for economizer operation, energy savings of the economizer in Miami were minimal.

### Impacts of Increased Outdoor Air Flows on Annual HVAC Energy Costs

It is commonly held that raising outdoor air flow rates to accommodate indoor air quality needs will dramatically increase energy use because this increased outdoor air must be conditioned. However, this conventional wisdom ignores the dynamics of energy use of different systems during different seasons. Exhibit 7 demonstrates that the annual average change in energy use resulting from increasing the outdoor air flow rate in an office building from 5 - 20 cfm per occupant depends on the relative impact of increases in energy use and decreases in energy use during different seasons. Significant reductions in cooling energy can occur in mild to cold temperatures which offset increases during warm weather, but heating penalties may also occur in CV systems during cold weather periods. The actual impact depends on the nature of the energy impact during each season, the utility rate structure, and the amount of time the system is operating within each seasonal range. Increases in CV systems tend to be higher than VAV systems because of the heating penalty in winter, while economizer systems tend to result in higher energy cost increases because much of the cooling cost savings in the mild to cold weather is already accounted for in the economizer system.

Exhibit 8 presents the HVAC energy cost changes when outdoor air flow rates are raised from 5 cfm (2 L/s) per occupant to 20 cfm (9 L/s) per occupant for the office building, and to 15 cfm (7 L/s) per occupant for the education and assembly buildings. All buildings have economizers. For the office building shown, the outdoor air increase resulted in only a 6% - 10% increase in HVAC energy cost, (or approximately 2% - 4% increase of total energy cost).

Raising outdoor air flow rates resulted in a considerably higher HVAC energy cost increase in the schools, amounting to 15% - 31% (5% - 14% total energy cost), while the auditorium experienced an HVAC energy cost increase of 26% - 67% (9% - 25% total energy cost). This was due to many factors. Because of the high occupant densities in these buildings, the required per occupant outdoor air flows may exceed supply air flow during periods of the year when thermal loads are low. In these cases, supply air flows must be increased to maintain minimum outdoor air flows in the building, increasing annual fan energy costs. This was done by adjusting the VAV box minimum settings. In addition, the large volumes of outdoor air subjected the cooling system to wide ranges in the sensible to latent heat ratio, making it difficult for the system to keep indoor air relative humidity below 60% when controlling only for temperature. Particularly on mild but humid days, indoor relative humidity frequently rose above 60% and occasionally rose above 70%. As a result, cooling coil temperatures had to be lowered when needed to insure that indoor relative humidity did not exceed 65%.

Contrary to conventional wisdom, the total increase in HVAC energy cost from raising the outdoor air flow rate in the education building and auditorium was least in Miami. While heating energy costs did not increase in the office buildings with a VAV system in any climate, heating cost penalties in the education and assembly buildings were substantial, often accounting for more than half of the increase in total HVAC energy cost in the cold and temperate climates. However, in the hot and humid climate of Miami, heating energy and fan energy penalties were very low. As a result, the total energy cost increase in Miami was less than it was in either Minneapolis or Washington, D.C.

## Impacts of Increased Outdoor Air Flows on HVAC System Capacity

Research on the impact of increased outdoor air flows on HVAC system capacity is important because ASHRAE Standard 62-1989 and the IAQ litigation environment may have the effect of forcing building operators to increase outdoor air flow rates in buildings in response to occupant complaints. When these situations occur, the existing cooling and heating systems (designed for 5 cfm of outdoor air per occupant) may not have the capacity to handle the increased load caused by the increased outdoor air flows.

Exhibit 9 presents DOE-2.1E predicted peak load impacts for the 3 types of buildings for VAV(COA) and the CV (FOAF) systems with economizers. While only economizer systems are presented, there were no meaningful differences in the results between systems with and without economizers Peak cooling load increases tended to be higher for the CV system than the VAV system, and also higher in the education and assembly buildings when compared to the office building. Increases in peak cooling loads ranged from 15% - 21% in the office building, from 20% - 33% in the education building, and from 26% to 45% in the assembly building. Increases tended to be higher in warmer climates5. Since increases in peak cooling loads caused by the increase in outdoor air occured during the day, capacity limitations on the cooling coil would most likely bring about thermal discomfort of occupants from midday to late afternoon.

Absolute increases in peak heating loads are modest (below 500 kBTU/hr) for all buildings in all climates, but percentage increases can be substantial due to relatively small initial peak loads. Peak preheat coil load increases can be higher (0 - 1100 kBTU/hr) and often occurred in situations where no preheat was required at the lower outdoor air flow rate. The increase in both the peak heating and peak preheat coil load caused by the increase in outdoor air occurred consistently at the first hour of occupancy when the outdoor air damper was first opened. This suggests that heating and preheat coil capacity limitations may therefore prevent the system from maintaining thermal comfort in the morning, and, with high outdoor air flow rates, potentially throughout the day. In the worst scenario, inadequate preheat capacity could result in coil damage if the outdoor dampers are not closed. But closing the outdoor dampers would add indoor air quality problems to the thermal comfort problems.

## The Energy Consequences of Protecting Indoor Environmental Quality in Energy Efficiency Projects

The indoor environmental factors that most influence occupant health and welfare are the thermal conditions, the lighting, and the concentrations of indoor pollutants. Thermal

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5 Peak cooling load increases show the same climatic pattern in Eto (1988)

control and lighting are familiar subjects in energy management. Accordingly, energy professionals are in a strong position to affect these two important aspects of indoor environmental quality (IEQ) while they are often less knowledgeable about indoor pollutant concentrations. Energy activities that are compatible with IEQ, either because they are likely to enhance or have little effect on IEQ if properly instituted, are identified in Exhibit 10. In general, the compatibility with IEQ is dependent on the cautions and adjustments which are outlined in this exhibit. In this modeling project, unless otherwise stated, the cautions and limitations described in this exhibit were either directly or implicitly incorporated into the modeling runs when energy efficiency measures were modeled.

Much of the perceived conflict between IEQ and energy efficiency derives from just two elements of an energy strategy– the tendency to minimize outdoor air ventilation rates and the willingness to relax controls on temperature and relative humidity to save energy. Energy reduction activities that are generally recognized as having a significant potential for degrading the indoor environment and causing problems for the building owner (client) and the occupants are identified in Exhibit 11.

A staged energy retrofit on an office building and education building was modeled to quantify the energy gains and losses from energy activities which protect or enhance indoor environmental quality and which avoid measures that compromise it. The office building had a VAV system with fixed outdoor air damper and an economizer, while the education building had a VAV system, constant outdoor air flow control and an economizer. The parameters of these buildings and the energy measures taken are presented in Exhibit 12. The staged retrofit included operational (tune-up) measures in Stage 1, load reduction measures in Stage 2, air distribution system upgrades in Stage 3, central plant upgrades in Stage 4, and selected IEQ upgrades in Stage 5. For analytic convenience, most of the operational measures normally included in Stage 1 were modeled and analyzed separately and not included in Stage 1.

Exhibits 13-14 present the energy cost results from the staged energy activities for the office building (Exhibit 13) and the education building (Exhibit 14). Exhibit 15 presents the percent savings (from the base and from the previous stage) of the total energy cost for both buildings[6].

Stage 1 included only a simple seasonal supply air temperature reset strategy which increased the supply air temperature from 55$^{0}$ F to 65$^{0}$F from January 1 to March 31 in each climate. Therefore, it does not reflect an optimal control logic for the fans and chiller. As a result, the energy savings for Stage 1 (-2% - 1%) are not substantial and not uniformly positive, and do not reflect values that would normally be achieved with a more sophisticated control strategy (See discussion of other operational measures below).

A further reduction beyond Stage 1 of 28% - 33% was achieved in this building through a lighting retrofit and increased efficiency of office equipment in Stage 2. The Stage 3 upgrades relied solely on variable speed drives which reduced the energy costs an additional 5% -10%. Finally, in Stage 4, central plant upgrades, including down-sizing the equipment because of reduced loads[7] added another 13% -15% to the total energy savings, bringing the combined savings to 44% - 45% for the office building. The results for the education building were similar but less dramatic, resulting in a total energy savings of 31% - 40%. While many of these activities implemented in Stages 1 through 4 above could impact IEQ, all the necessary adjustments identified in Exhibit 10 were made or are implicit in the model's algorithms to insure that IEQ would not be degraded.

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[6] Total energy costs are defined here to include only energy from HVAC, lighting, and office equipment.

The base buildings provided only 5 cfm of outdoor air per occupant (i.e. does not meet the current ASHRAE ventilation requirements for indoor air quality (ASHRAE Standard 62-1989)). To meet the requirements of ASHRAE Standard 62-1989, a set of IEQ controls were instituted as part of Stage 5. The first control was to raise the outdoor air setting from 5 cfm per occupant to 20 cfm per occupant in the office building, and 15 cfm per occupant in the education building. The second control was to provide a constant outdoor air control damper to the office building to insure 20 cfm of outdoor air per occupant at all times. In the education building, VAV boxes were adjusted to insure 15 cfm per occupant at all times, and relative humidity was controlled so as not to exceed 60%.

Meeting these indoor environmental requirements raised total energy costs 3% -4% for the office building and 5% - 14% for the education building. Accordingly, the staged energy retrofits which include provisions to protect indoor environmental quality and which provide additional outdoor air to meet ASHRAE Standard 62-1989 achieved total energy savings of 42% - 43% for the office building, and 22% - 37% for the education building. While the modeling capability in DOE-2.1E does not allow adequate representation of energy recovery systems, some literature suggests that the energy burden of providing additional outdoor air can be substantially reduced or eliminated through energy recovery technology (Rengarajan, el al. 1996; Shirey and Rengarajan, 1996). This issue is worthy of further research.

Many energy measures with significant potential to adversely impact IEQ occur in Stage 1, and involve either relaxing temperature (and humidity) controls and/or reducing HVAC operating hours. Exhibit 16 summarizes the results of these modeling runs. Widening the day time temperature dead band from 71 - 77° F to 68-80° F reduced energy costs by 2% - 3% in the office building, and by 7% - 8% in the education building. Relaxing the night time temperature setback from +/- 10°F to +/- 15°F reduced energy costs from 0% - 1% in the office and from 1% - 2% in the education building. Reducing the HVAC operating time by two hours (including a reduction of startup time from 2 hours to 1 hour), reduced the energy costs by 0% - 1% for the office building and by 2% - 4% in the education building. All of these operational measures are attractive because they are inexpensive to implement. However, the savings are small relative to other operational measures or retrofit measures, and cumulatively amount to savings of only 3%-5% for the office building and to 7% - 10% in the education building.

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[7] The equipment was downsized, but not below that necessary to accommodate increased outdoor air flow in Stage 5 of 20 cfm/occ for the office building, and 15 cfm per occupant for the education building as per ASHRAE Standard 62-1989.

In contrast, other operational measures for Stage 1 that do not degrade IEQ can provide significant savings. For example, simply commissioning the building to insure that controls and equipment are functioning properly (not modeled) have been shown to typically reduce total energy costs by 5% - 15%, and also tend to improve IEQ (Gregerson, 1997). Reducing lighting and office equipment usage during unoccupied hours can also result in significant savings. The base office building was modeled with lighting during unoccupied hours operated at 20% of daytime use and office equipment operated at 30% of daytime use. Exhibit 17 compares the modeling results for this case (20%/30%) with both greater usage during unoccupied hours (40% /50%) in Stage 1, and reduced usage (10%/15%) after Stage 4 modifications.

As indicated in Exhibit 17, had the usage of the lighting/office equipment during unoccupied hours been at 40%/50% of day time levels and then reduced to the original levels of 20%/30% that was modeled in the office building, 12% savings would have been possible in Stage 1 from this activity. This result is consistent with field data which showed that energy savings of 15% on average are associated with operational controls (mostly lighting) during unoccupied hours (Herzog, et al.1992). In addition, an aggressive program to reduce night time use of lights and office equipment after the building is made energy efficient and IEQ compatible could provide additional reductions of equal magnitude.

## Summary

This study contains DOE-2.1E modeling data and analysis which shed light on several important issues related to the performance of ventilation systems in terms of energy use, thermal comfort, and outdoor air flow. The results of this study suggest that some systems perform better than others. Special problems in controlling the indoor climate for very high occupant density buildings such as schools and auditoriums were identified as were the issues of reducing energy costs in solving these problems. Finally, the study suggest certain guidelines for protecting or enhancing indoor environmental quality during energy efficiency projects.

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Exhibit 1: Characteristics of the Base Buildings Modeled in this Study

| | Office | Education | Assembly |
|---|---|---|---|
| **Building Characteristics** | | | |
| Shape | square | L-shaped | square |
| Zones/Floor | 5 | 6 | 5 |
| Floor Area (ft2) | 338,668 | 50,600 | 19,600 |
| Number of Floors | 12 | 2 | 1 |
| Floor Height (ft) | 12 | 15 | 30 |
| Wall Construction | steel-reinforced concrete, curtain wall | concrete block | concrete block |
| Net Window Area (%) | 42% | 34% | 7% |
| Window U-factor (Btu/hr ft2 0F) | 0.75 | 0.59 | 0.59 |
| Window Shading Coefficient | 0.8 | 0.6 | 0.6 |
| Wall R-Value (hr ft2 0F/Btu) | R-7 | R-8 | R-8 |
| Roof R-Value (hr ft2 0F/Btu) | R-8 | R-12 | R-12 |
| Perimeter/Core Ratio* | 0.5 | 1.0 | 0.6 |
| Infiltration Rate (ach) | 0.25** | 0.25 | 0.25 |
| **Occupancy** | | | |
| Number of Occupants | 2,130 | 1,518 | 588 |
| Occupant Density (occup/1000ft2) | 7 | 30 | 60 |
| **HVAC** | | | |
| Air Distribution System | central (CVor VAV) | central (CVor VAV) | central (CVor VAV) |
| Heating and DHW | central gas boiler - 70% efficiency | central gas boiler - 80% efficiency | central gas boiler - 80% efficiency |
| Cooling | chiller - 3 COP w/cooling tower | chiller - 4 COP w/cooling tower | chiller - 4 COP w/cooling tower |

* Ratio of perimeter to core floor area, where perimeter space is up to 15 ft. from the exterior walls

**0.5 when HVAC is not operating

*Exhibit* 3: Comparison of Outdoor Air Flows {design = 20 cfm (9 L/s) per person} for a Large Office Building with Alternative HVAC Systems

**(% of Occupied Hours )**

| HVAC System Type and Climate Location | Outdoor Air Flow Rates Achieved (cfm per person) | | | | |
|---|---|---|---|---|---|
| | <= 5 | 6-10 | 11-15 | 16-19 | >= 20 |
| CV(FOAF) | | | | | |
| Minneapolis, MN | 0.0% | 0.0% | 0.0% | 0.0% | 100.0% |
| Washington, DC | 0.0% | 0.0% | 0.0% | 0.0% | 100.0% |
| Miami, FL | 0.0% | 0.0% | 0.0% | 0.0% | 100.0% |
| VAV(COA) | | | | | |
| Minneapolis, MN | 0.0% | 0.0% | 0.0% | 0.0% | 100.0% |
| Washington, DC | 0.0% | 0.0% | 0.0% | 0.0% | 100.0% |
| Miami, FL | 0.0% | 0.0% | 0.0% | 0.0% | 100.0% |
| VAV(FOAF) | | | | | |
| Minneapolis, MN | 0.0% | 42.0% | 56.3% | 1.7% | 0.0% |
| Washington, DC | 0.0% | 16.6% | 78.1% | 5.3% | 0.0% |
| Miami, FL | 0.0% | 0.0% | 42.5% | 57.5% | 0.0% |
| VAV(FOAF) Econ | | | | | |
| Minneapolis, MN | 0.0% | 0.0% | 32.5% | 0.0% | 67.4% |
| Washington, DC | 0.0% | 0.1% | 48.6% | 0.5% | 50.8% |
| Miami, FL | 0.0% | 0.0% | 62.3% | 31.9% | 5.8% |

Exhibit 5: Comparison of Zone Level Outdoor Air Flow Rates {design = 20 cfm (9 L/s) per person} for Three Types of HVAC Systems in Office Buildings in Washington, DC.

**(% of Occupied Hours)**

| System Type and Zone | without Economizer | | | | | with Economizer | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | OA Flow Rate Achieved (cfm/person) | | | | | OA Flow Rate Achieved (cfm/person) | | | | |
| | <6 | 6-10 | 11-15 | 16-19 | >19 | <6 | 6-10 | 11-15 | 16-19 | >19 |
| CV(FOAF) | | | | | | | | | | |
| Core | | | 100.0 | | | | | 49.9 | 0.6 | 49.5 |
| East | | | | | 100.0 | | | | | 100.0 |
| North | | | | | 100.0 | | | | | 100.0 |
| West | | | | | 100.0 | | | | | 100.0 |
| South | | | | | 100.0 | | | | | 100.0 |
| VAV(COA) | | | | | | | | | | |
| Core | | 0.2 | 51.5 | 48.3 | 0.0 | | | 39.0 | 10.4 | 50.6 |
| East | | | | | 100.0 | | | | | 100.0 |
| North | | | | 14.4 | 85.6 | | | | 4.1 | 95.9 |
| West | | | | | 100.0 | | | | | 100.0 |
| South | | | | | 100.0 | | | | | 100.0 |
| VAV(FOAF) | | | | | | | | | | |
| Core | 0.7 | 99.3 | 0.0 | 0.0 | 0.0 | | 49.3 | 0.1 | 0.1 | 50.6 |
| East | | | 46.4 | 15.3 | 38.3 | | | 6.3 | 13.5 | 80.2 |
| North | | | 69.4 | 24.4 | 6.2 | | 3.5 | 19.4 | 23.8 | 53.2 |
| West | | | 54.2 | 15.0 | 30.8 | | | 9.7 | 14.5 | 75.7 |
| South | | | 35.2 | 10.7 | 54.1 | | | 6.1 | 8.8 | 85.1 |

Exhibit 6: Comparison of Annual Energy Costs for the Base Office Building with Alternative HVAC Systems and in Different Climates

| HVAC System Type and Climate Location | Annual HVAC Energy Use Summary | | | | |
|---|---|---|---|---|---|
| | Fan ($/SF) | Cooling ($/SF) | Heating ($/SF) | Total ($/SF) | (KBtu/sf) |
| CV(FOAF) | | | | | |
| Minneapolis, MN | 0.32 | 0.52 | 0.04 | 0.88 | 47.4 |
| Washington, DC | 0.29 | 0.56 | 0.01 | 0.86 | 41.1 |
| Miami, FL | 0.30 | 0.72 | 0.00 | 1.02 | 50.6 |
| CV(FOAF) Econ | | | | | |
| Minneapolis, MN | 0.32 | 0.45 | 0.10 | 0.87 | 53.7 |
| Washington, DC | 0.29 | 0.50 | 0.06 | 0.85 | 46.4 |
| Miami, FL | 0.30 | 0.71 | 0.00 | 1.01 | 50.7 |
| VAV(COA) | | | | | |
| Minneapolis, MN | 0.19 | 0.49 | 0.10 | 0.78 | 49.7 |
| Washington, DC | 0.17 | 0.52 | 0.05 | 0.74 | 38.9 |
| Miami, FL | 0.18 | 0.65 | 0.00 | 0.83 | 38.9 |
| VAV(COA) Econ | | | | | |
| Minneapolis, MN | 0.19 | 0.43 | 0.11 | 0.73 | 45.9 |
| Washington, DC | 0.17 | 0.47 | 0.05 | 0.69 | 35.8 |
| Miami, FL | 0.18 | 0.64 | 0.00 | 0.83 | 36.5 |
| VAV(FOAF) | | | | | |
| Minneapolis, MN | 0.19 | 0.49 | 0.10 | 0.79 | 50.6 |
| Washington, DC | 0.17 | 0.52 | 0.05 | 0.74 | 39.5 |
| Miami, FL | 0.18 | 0.62 | 0.00 | 0.81 | 38.3 |
| VAV(FOAF) Econ | | | | | |
| Minneapolis, MN | 0.19 | 0.42 | 0.11 | 0.71 | 45.7 |
| Washington, DC | 0.17 | 0.46 | 0.05 | 0.68 | 35.5 |
| Miami, FL | 0.18 | 0.61 | 0.00 | 0.80 | 37.8 |

Exhibit 8: Annual HVAC Energy Costs of Increasing Outdoor Air from 5 to 20 cfm per person for VAV(COA) Systems with Economizers

| Climate | Office Building | | | Education Building | | | Assembly Building | | |
|---|---|---|---|---|---|---|---|---|---|
| End Use | 5 cfm ($/sf) | Increase ($/sf) | Percent Increase (%) | 5 cfm ($/sf) | Increase ($/sf) | Percent Increase (%) | 5 cfm ($/sf) | Increase ($/sf) | Percent Increase (%) |
| Minneapolis, MN | | | | | | | | | |
| Fan | 0.19 | 0.00 | None | 0.17 | 0.01 | 5% | 0.24 | 0.06 | 24% |
| Cooling | 0.39 | 0.04 | 10% | 0.35 | 0.07 | 19% | 0.49 | 0.18 | 37% |
| Heating | 0.10 | 0.00 | None | 0.32 | 0.19 | 59% | 0.58 | 0.64 | 111% |
| Total | 0.69 | 0.04 | 6% | 0.84 | 0.27 | 32% | 1.31 | 0.88 | 67% |
| Washington, DC | | | | | | | | | |
| Fan | 0.17 | 0.00 | None | 0.16 | 0.01 | 6% | 0.23 | 0.06 | 26% |
| Cooling | 0.42 | 0.05 | 12% | 0.40 | 0.10 | 25% | 0.61 | 0.20 | 33% |
| Heating | 0.05 | 0.00 | None | 0.14 | 0.11 | 81% | 0.23 | 0.38 | 162% |
| Total | 0.65 | 0.05 | 8% | 0.70 | 0.22 | 31% | 1.07 | 0.64 | 60% |
| Miami, FL | | | | | | | | | |
| Fan | 0.18 | 0.00 | None | 0.20 | 0.00 | None | 0.29 | 0.03 | 11% |
| Cooling | 0.57 | 0.07 | 13% | 0.64 | 0.12 | 18% | 1.09 | 0.31 | 29% |
| Heating | 0.00 | 0.00 | None | 0.00 | 0.00 | None | 0.00 | 0.01 | 786% |
| Total | 0.75 | 0.08 | 10% | 0.84 | 0.13 | 15% | 1.39 | 0.36 | 26% |

Exhibit 9: Impacts of Increased Outdoor Air Flows on Peak HVAC Coil Loads for VAV(COA) Systems with Economizers

| Climate | Office Building | | | Education Building | | | Assembly Building | | |
|---|---|---|---|---|---|---|---|---|---|
| End Use | 5 cfm (kBTU/Hr) | Increase (kBTU/Hr) | Percent Increase (%) | 5 cfm (kBTU/Hr) | Increase (kBTU/Hr) | Percent Increase (%) | 5 cfm (kBTU/Hr) | Increase (kBTU/Hr) | Percent Increase (%) |
| Minneapolis, MN | | | | | | | | | |
| Cooling | 8688 | 1336 | 15% | 1841 | 370 | 20% | 958 | 271 | 28% |
| Heating | 6148 | 444 | 7% | 2819 | 1 | 0% | 1134 | 106 | 9% |
| Preheat | 0 | 897 | Increase | 246 | 1282 | 521% | 330 | 919 | 279% |
| Washington, DC | | | | | | | | | |
| Cooling | 8517 | 1659 | 19% | 1951 | 488 | 25% | 1067 | 275 | 26% |
| Heating | 4638 | None | None | 1935 | 93 | 5% | 822 | 177 | 22% |
| Preheat | 0 | None | None | 90 | 750 | 832% | 224 | 553 | 247% |
| Miami, FL | | | | | | | | | |
| Cooling | 8670 | 1862 | 21% | 2213 | 529 | 24% | 1229 | 349 | 28% |
| Heating | 1949 | None | None | 397 | 271 | 68% | 99 | 291 | 293% |
| Preheat | 0 | None | None | 0 | 200 | Increase | 0 | 151 | Increase |

Exhibit 10: Energy Measures that are Compatible with IEQ

| Measure | Comment |
|---|---|
| Improve building shell | - May reduce infiltration. May need to increase mechanically supplied outdoor air to ensure applicable ventilation standards are met. |
| Reduce internal loads (e.g. lights, office equipment) | - Reduced loads will reduce supply air requirements in VAV systems. May need to increase outdoor air to meet applicable ventilation standards.<br>- Lighting must be sufficient for general lighting and task lighting needs |
| Fan/motor/drives | - Negligible impact on IEQ |
| Chiller/ boiler | - Negligible impact on IEQ |
| Energy recovery | - May reduce energy burden of outdoor air, especially in extreme climates and/or when high outdoor air volumes are required (e.g. schools, auditoria). |
| Air-side economizer | - Uses outdoor air to provide free cooling. Potentially improves IEQ when economizer is operating by helping to ensure that the outdoor air ventilation rate meets IEQ requirements.<br>- On/off set points should be calibrated to both the temperature and moisture conditions of outdoor air to avoid indoor humidity problems. May need to disengage economizer during an outdoor air pollution episode. |
| Night pre-cooling | - Cool outdoor air at night may be used to pre-cool the building while simultaneously exhausting accumulated pollutants. However, to prevent microbiological growth, controls should stop pre-cooling operations if dew point of outdoor air is high enough to cause condensation on equipment. |
| Preventive Maintenance (PM) of HVAC | - PM will improve IEQ and reduce energy use by removing contaminant sources (e.g. clean coils/drain pans), and insuring proper calibration and efficient operation of mechanical components (e.g. fans, motors, thermostats, controls).. |
| CO2 controlled ventilation | - CO2 controlled ventilation varies the outdoor air supply in response to CO2 which is used as an indicator of occupancy. May reduce energy use for general meeting rooms, studios, theaters, educational facilities etc. where occupancy is highly variable, and irregular. A typical system will increase outdoor air when CO2 levels rise to 600-800 ppm to ensure that maximum levels do not exceed 1,000 ppm. The system should incorporate a minimum outside air setting to dilute building related contaminants during low occupancy periods. |
| Reducing demand (KW) charges | - Night pre-cooling and sequential startup of equipment to eliminate demand spikes are examples of strategies that are compatible with IEQ. Caution is advised if load shedding strategies involve changing the space temperature set points or reducing outdoor air ventilation during occupancy. |
| Supply air temperature reset | - Supply air temperature may sometimes be increased to reduce chiller energy use. However, fan energy will increase. Higher supply air temperatures in a VAV system will increase supply air flow and vice versa. |
| Equipment down-sizing | - Prudent avoidance of over-sizing equipment reduces first costs and energy costs. However, capacity must be sufficient for thermal and outdoor air requirements during peak loads in both summer and winter. Latent load should not be ignored when sizing equipment in any climate. Inadequate humidity control has resulted in thermal discomfort and mold contamination so great as to render some buildings uninhabitable.<br>- Energy recovery systems may enable chillers and boilers to be further downsized by reducing the thermal loads from outdoor air ventilation. |

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Exhibit 11: Energy Measures that May Degrade IEQ

| Measure | Comment |
|---|---|
| Reducing outdoor air ventilation | - Applicable ventilation standards usually specify a minimum continuous outdoor air flow rate per occupant, and/or per square foot, during occupied hours. They are designed to ensure that pollutants in the occupied space are sufficiently diluted with outdoor air. Reducing outdoor air flow below applicable standards can degrade IEQ and has low energy saving potential relative to other energy saving options. |
| Variable Air Volume (VAV) Systems with fixed percentage outdoor air | - VAV systems can yield significant energy savings over Constant Volume (CV) systems in many applications. However, many VAV systems provide a fixed percentage of outdoor air (e.g. fixed outdoor air dampers) so that during part load conditions when the supply air is reduced, the outdoor air may also be reduced to levels below applicable standards.<br>- VAV systems should employ controls which maintain a continuous outdoor air flow consi[illegible] applicable standards. Hardware is now available from vendors and involves no significant energy penalty. |
| Reducing HVAC operating hours | Delayed start-up or premature shutdown of the HVAC can evoke IEQ problems and occupant complaints.<br>- An insufficient lead time prior to occupancy can result in thermal discomfort and pollutant-related health problems for several hours as the HVAC system must overcome the loads from both the night-time setbacks and from current occupancy. This is a particular problem when equipment is downsized. Shutting equipment down prior to occupants leaving may sometimes be acceptable provided that fans are kept operating to ensure adequate ventilation. However, the energy saved may not be worth the risk . |
| Relaxation of thermal control | Some energy managers may be tempted to allow space temperatures or humidity to go beyond the comfort range established by applicable standards. Occupant health, comfort and productivity are compromised. The lack of overt occupant complaints is NOT an indication of occupant satisfaction. |

Exhibit 12: Modeling Parameters for the Office and Education Building

| Building Parameter | Office Building | | Education Building | |
|---|---|---|---|---|
| | Base | Modification | Base* | Modification |
| Stage 1: Operational/Tune-up Measures | | | | |
| Day Temp. Set Points | 71o - 77o F | (68o - 80o F) | 71o - 77o F | (68o - 80o F) |
| Night Set Back | +/- 10o F | (+/- 15o F ) | +/- 10o F | (+/- 15o F) |
| Day HVAC Hours | 8am - 6pm | (9am - 5pm) | 7am -10pm | (8am - 9pm) |
| Seasonal Reset | No | Yes | No | Yes |
| Entries in parentheses were modeled separately–not part of the retrofit project | | | | |
| Stage 2: Load Reduction Measures | | | | |
| Lighting | 2.5 W/f2 | 30% reduction | 3.0 W/f2 rms<br>2.0 W/f2 corr | 30% reduction |
| Office Equipment | 1.0 W/f2 | 30% reduction | 0.25 W/f2 | 30% reduction |
| Stage 3: Air distribution System Upgrades | | | | |
| VSD | no | yes | no | yes |
| Stage 4: Central Plant Upgrades | | | | |
| Chiller COP | 3.0 | 5.5 | 3.0 | 5.5 |
| Boiler Efficiency | 70% | 85% | 70% | 85% |
| Stage 5: IEQ Ventilation Modifications Required to meet ASHRAE 62-1989 | | | | |
| Outdoor Air Setting | 5 cfm/occ | 20 cfm/occ | 5 cfm/occ | 15 cfm/occ |
| Outdoor Air Control | fixed damper | constant flow | constant flow | const. flow-VAV box adjustment |
| Humidity Control | not needed | not needed | not needed | 60% RH |

*For the base education building used for the energy retrofit: infiltration rate = 0.5ach; window U value = 0.99 (Btui/hr ft$^2$ $^0$F); and window shading coeff. = 0.90.

Exhibit 13: Energy Cost for Office Building with Energy and IEQ Modifications

| Building Parameter | Washington D.C.<br>($/sf) | | | | | | Minneapolis<br>($/sf) | | | Miami<br>($/sf) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Fan | Cool | Heat | Total HVAC | Light & Off. Equip | Total | Total HVAC | Light & Off. Equip | Total | Total HVAC | Light & Off. Equip | Total |
| Base Bldg | 0.17 | 0.42 | 0.05 | 0.64 | 0.94 | 1.58 | 0.68 | 0.94 | 1.62 | 0.74 | 0.94 | 1.68 |
| Stage 1<br>Seas. Reset | 0.18 | 0.41 | 0.04 | 0.63 | 0.94 | 1.57 | 0.66 | 0.94 | 1.60 | 0.78 | 0.94 | 1.72 |
| Stage 2<br>Ltng/Off Equip | 0.15 | 0.30 | 0.08 | 0.52 | 0.57 | 1.08 | 0.58 | 0.57 | 1.16 | 0.57 | 0.57 | 1.15 |
| Stage 3<br>VSD | 0.09 | 0.28 | 0.06 | 0.43 | 0.57 | 1.00 | 0.47 | 0.57 | 1.04 | 0.52 | 0.57 | 1.09 |
| Stage 4<br>Chiller/Boiler | 0.09 | 0.16 | 0.05 | 0.30 | 0.57 | 0.87 | 0.33 | 0.57 | 0.90 | 0.35 | 0.57 | 0.93 |
| Stage 5 | | | | | | | | | | | | |
| OA Setting | 0.09 | 0.18 | 0.06 | 0.32 | 0.57 | 0.89 | 0.36 | 0.57 | 0.93 | 0.38 | 0.57 | 0.95 |
| OA Control | 0.09 | 0.19 | 0.06 | 0.33 | 0.57 | 0.90 | 0.37 | 0.57 | 0.94 | 0.40 | 0.57 | 0.9 |

Exhibit 14: Energy Cost for the Education Building with Energy and IEQ Modifications

| Building Parameter | Washington D.C.<br>($/f2) | | | | | | Minneapolis<br>($/f2) | | | Miami<br>($/f2) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Fan | Cool | Heat | Total HVAC | Light & Off Equip | Total | Total HVAC | Light & Off Equip | Total | Total HVAC | Light & Off. Equip | Total |
| Base Bldg | 0.21 | 0.62 | 0.28 | 1.11 | 0.97 | 2.08 | 1.42 | 0.97 | 2.40 | 1.22 | 0.97 | 2.19 |
| Stage 1<br>Seasonal Reset | 0.21 | 0.61 | 0.25 | 1.07 | 0.97 | 2.04 | 1.38 | 0.97 | 2.36 | 1.23 | 0.97 | 2.21 |
| Stage 2<br>Lights/off equip | 0.19 | 0.53 | 0.33 | 1.04 | 0.67 | 1.71 | 1.42 | 0.67 | 2.10 | 1.08 | 0.67 | 1.76 |
| Stage 3<br>VSD | 0.11 | 0.50 | 0.33 | 0.94 | 0.67 | 1.62 | 1.30 | 0.67 | 1.97 | 0.98 | 0.67 | 1.65 |
| Stage 4<br>Chiller/boiler | 0.11 | 0.29 | 0.28 | 0.67 | 0.67 | 1.35 | 0.98 | 0.67 | 1.65 | 0.64 | 0.67 | 1.31 |
| Stage 5* | | | | | | | | | | | | |
| OA Setting | 0.12 | 0.35 | 0.35 | 0.82 | 0.67 | 1.49 | 1.19 | 0.67 | 1.68 | 0.73 | 0.67 | 1.40 |
| OA & RH control | 0.13 | 0.36 | 0.38 | 0.87 | 0.67 | 1.54 | 1.20 | 0.67 | 1.87 | 0.71 | 0.67 | 1.38 |

*Only the education building required RH control

Exhibit 15: Percent Savings in Total Energy Cost from Energy and IEQ Modifications

*(Top figure in each cell is for office building; bottom figure is for education building)*

| | Washington | | | Minneapolis | | | Miami | | |
|---|---|---|---|---|---|---|---|---|---|
| | $/f2 | From Base | From Prev. Stage | $/f2 | From Base | From Prev. Stage | $/f2 | From Base | From Prev. Stage |
| Base Bldg | 1.58<br>2.08 | | | 1.62<br>2.40 | | | 1.68<br>2.19 | | |
| Stage 1<br>Seasonal Reset | 1.57<br>2.04 | 01%<br>02% | 01%<br>02% | 1.60<br>2.36 | 01%<br>2% | 01%<br>2% | 1.74<br>2.21 | -02%<br>-01% | -02%<br>-01% |
| Stage 2<br>Lights/Off Equip | 1.08<br>1.71 | 32%<br>18% | 31%<br>16% | 1.16<br>2.10 | 28%<br>13% | 28%<br>11% | 1.15<br>1.76 | 32%<br>20% | 33%<br>20% |
| Stage 3<br>VSD | 1.00<br>1.62 | 37%<br>22% | 07%<br>05% | 1.04<br>1.97 | 36%<br>18% | 10%<br>6% | 1.09<br>1.65 | 35%<br>25% | 5%<br>6% |
| Stage 4<br>Chiller/boiler | 0.87<br>1.35 | 45%<br>35% | 13%<br>17% | 0.90<br>1.65 | 44%<br>31% | 13%<br>16% | 0.93<br>1.31 | 45%<br>40% | 15%<br>21% |
| Stage 5*<br>OA setting with OA & RH control | 0.90<br>1.54 | 43%<br>26% | -03%<br>-14% | 0.94<br>1.87 | 42%<br>22% | -04%<br>-13% | 0.97<br>1.38 | 42%<br>37% | -04%<br>-05% |

* Only the education building required RH control

Exhibit 16: Energy Costs of Operational Measures that May Have Adverse Effects on IEQ

| Building Parameter | Washington D.C. $/sf | | | | | | | Minneapolis $/sf | | | Miami $/sf | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Fan | Cool | Heat | Total HVAC | Light & Off Equip | Total | % Save | Total HVAC | Total | % Save | Total HVAC | Total | % Save |
| Base Off. Bldg | 0.17 | 0.42 | 0.05 | 0.64 | 0.94 | 1.58 | | 0.68 | 1.62 | | 0.74 | 1.68 | |
| Day Temp. Set | 0.17 | 0.40 | 0.04 | 0.61 | 0.94 | 1.56 | 01% | 0.64) | 1.58 | 03% | 0.71 | 1.65 | 02% |
| Night Set Back | 0.16 | 0.41 | 0.04 | 0.62 | 0.94 | 1.56 | 01% | 0.66 | 1.60 | 01% | 0.72 | 1.66 | 01% |
| Day HVAC Hrs. | 0.17 | 0.42 | 0.04 | 0.63 | 0.94 | 1.57 | 01% | 0.66 | 1.60 | 01% | 0.75 | 1.69 | 00% |
| Base Edu. Bldg | 0.21 | 0.62 | 0.28 | 1.11 | 0.97 | 2.08 | | 1.42 | 2.40 | | 1.22 | 2.19 | |
| Day Temp. Set | 0.18 | 0.55 | 0.22 | 0.95 | 0.97 | 1.93 | 07% | 1.25 | 2.23 | 07% | 1.06 | 2.03 | 01% |
| Night Set Back | 0.21 | 0.62 | 0.27 | 1.10 | 0.97 | 2.07 | 00% | 1.40 | 2.38 | 01% | 1.22 | 2.19 | 00% |
| Day HVAC Hrs | 0.20 | 0.61 | 0.25 | 1.06 | 0.97 | 2.02 | 03% | 1.34 | 2.31 | 04% | 1.18 | 2.15 | 02% |

Exhibit 17: Savings from Reduced Lights and Office Equipment when Unoccupied

| Operational Control | Office Building in Washington D.C. | | | | |
|---|---|---|---|---|---|
| % of daytime use during unoccupied hours | Energy Cost ($/f 2) | | | Saving | |
| | HVAC | Light/off equip | Total | $/f2 | % |
| Stage 1 | | | | | |
| 40% lights/50% office equipment (base case) | 0.71 | 1.08 | 1.79 | | |
| 20% lights/30% office equipment | 0.64 | 0.94 | 1.58 | 0.21 | 12% |
| Stage 4 (retrofitted building) | | | | | |
| 20% lights/30% office equipment | 0.33 | 0.57 | 0.90 | | |
| 15%lights/20% office equipment | 0.29 | 0.40 | 0.70 | 0.20 | 22% |

# APPENDIX E – LIGHTING DESIGN SUPPLEMENT

In this manual, the Electric Lighting and Controls chapter and the Daylighting and Fenestration Design chapter both provide general information about designing lighting systems for schools, as well as detailed recommendations in the form of guidelines. This appendix offers supplemental information about lighting and daylighting design lighting practitioners may find useful.

This supplement provides an overview of the new IESNA lighting design process, and technical information about light sources and ballasts, luminaires and controls.

## IESNA Lighting Design Process

In the 9th edition of the *Lighting Handbook: Design and Application*, IESNA published a new lighting design procedure for schools and other buildings. Previous design procedures stressed horizontal illumination as the major design criteria, based on the type of visual task being performed. The new procedure comprises a six-step process consisting of the following:

1. Using the Lighting Design Guide found in Chapter 10 of the new *Lighting Handbook*, find the appropriate visual task or location under consideration.
2. Learn about which "design issues" (see below) are important for that visual task or location. Issues are identified as being "very important," "somewhat important," or "somewhat important," wherever applicable.
3. Refer to the appropriate application chapter of the *Handbook*, as directed in the Lighting Design Guide.
4. Go to other chapters of the *Handbook* for discussions of how to apply the relevant design criteria, and for a better understanding of the issues that are not included in the Design Guide.
5. From the Lighting Design Guide, determine the targets for horizontal and vertical illuminance. Use professional judgment as to whether or not these values need to be adjusted for factors such as low reflectances.
6. Document the process.

Admittedly the more proficient designer will find much of this process to be intuitive in nature; however steps 1, 3, and 5 are critical for optimum lighting effectiveness and efficiency.

## Design Issues

Design issues found in step 3 of the IESNA lighting design procedure are as follows:

- Appearance of Space & Luminaires
- Color Appearance
- Daylighting Integration and Control
- Direct Glare
- Flicker & Strobe
- Light Distribution on Surfaces
- Light Distribution on Task Plane (Uniformity)
- Luminances of Room Surfaces
- Modeling of Faces or Clients
- Point(s) of Interest
- Reflected Glare
- Shadows
- Source/Task/Eye Geometry
- Sparkle/Desirable Reflected Highlights
- Surface Characteristics
- System Control & Flexibility
- Horizontal Illuminance
- Vertical Illuminance

Each of these design issues is assigned a value based on their importance. Issues that are considered most important in school lighting vary depending on space type. Specific spaces listed for educational facilities include corridors, many different types of classroom, gymnasiums, outdoor sports facilities, cafeterias, and dormitories. In addition, as shown in table 1, more than 30 separate reading tasks are listed, with differing design issues.

*Table 1: Design Issues for Reading Tasks*

*Source IESNA, 9th Edition Lighting Handbook, Reference and Applications, Chapter 10*

**I. INTERIOR LOCATIONS AND TASKS**

■ Very Important ▨ Important □ Somewhat important □ Blank = Not important or not applicable

| Design Issues | Appearance of Space and Luminaires | Color Appearance (and Color Contrast) | Daylighting Integration and Control | Direct Glare | Flicker (and Strobe) | Light Distribution on Surfaces | Light Distribution on Task Plane (Uniformity | Luminances of Room Surfaces | Modeling of Faces or Objects | Point(s) of Interest | Reflected Glare | Shadows | Source/Task/Eye Geometry | Sparkle/Desirable Reflected Highlights | Surface Characteristics | System Control and Flexibility | Special Considerations | Notes on Special Considerations | Illuminance (Horizontal) | Category or Value (lux) | Illuminance (Vertical) | Category or Value (lux) | Notes on Illuminance - see end of section | Reference Chapter(s) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Reading** (16) | | | | | | | | | | | | | | | | | | | | | | | | Ch. 11, 12 |
| | | | | | | | | | | | | | | | | | | | | | | | | |
| Copied tasks | | | | | | | | | | | | | | | | | | | | | | | | |
| Microfiche reader | | | | | | | | | | | ■ | | ■ | | | ■ | | | | A | | A | | |
| Photograph, moderate detail | | ■ | | | | | | | | | ■ | | ■ | | | | | | ■ | E | | | | |
| Thermal copy, poor | | | | | | | | | | | ■ | | ■ | | | | | | ■ | F | | | | |
| Photocopies | | | | | | | | | | | ■ | | | | | | | | ■ | D | | | | |
| Photocopies, 3rd generation | | | | | | | | | | | ■ | | ■ | | | | | | ■ | E | | | | |
| Data processing tasks | | | | | | | | | | | | | | | | | | | | | | | | |
| VDT screens | ▨ | | ▨ | ■ | | ▨ | ■ | ▨ | | | ■ | ▨ | ■ | | | ▨ | | | ▨ | A | ■ | A | | |
| Impact printer | | | | | | | | | | | | | | | | | | | | | | | | |
| good ribbon | | | | | | | | | | | | | ▨ | | | | | | ■ | D | | | | |
| 2nd carbon and greater | | | | | | | ▨ | | | | | | ■ | | | | | | ■ | E | | | | |
| ink jet/laser printer | | | | | | | | | | | | | | | | | | | ▨ | D | | | | |
| keyboard reading | | | | | | | | | | | | ▨ | | | | | | | ▨ | D | | | | |
| Machine rooms | | | | | | | | | | | | | | | | | | | | | | | | |
| Active operations | | | | | | | | | | | | | | | | | | | ▨ | D | | | | |
| Tape storage | | | | | | | | | | | | | | | | | | | | D | ▨ | B | | |
| Machine area | | | | | | | | | | | | | | | | | | | | C | | | | |
| Equipment service | | | | | | | | | | | | | ▨ | | | | | | ▨ | E | ▨ | C | | |
| Thermal print | | | | | | | | | | | ■ | | ■ | | | | | | ▨ | E | | | | |
| Handwritten tasks | | | | | | | | | | | | | | | | | | | | | | | | |
| #2 pencil and softer leads | | | | | | | | | | | ■ | | ▨ | | | | | | ■ | D | | | | |
| #3 pencil | | | | | | | ▨ | | | | ■ | | ■ | | | | | | ■ | E | | | | |
| #4 pencil and harder leads | | | | | | | ▨ | | | | ■ | | ■ | | | | | | ■ | F | | | | |
| Ball-point pen | | | | | | | | | | | ■ | | | | | | | | ▨ | D | | | | |
| Felt-tip pen | | | | | | | | | | | ▨ | | | | | | | | ▨ | D | | | | |
| Handwritten carbon copy | | | | | | | ▨ | | | | | | ■ | | | | | | ■ | E | | | | |
| White boards | | ▨ | ▨ | | | ▨ | ▨ | ▨ | | | ■ | ▨ | ■ | | ▨ | ▨ | | | | | ■ | B | | |
| Chalk boards | | ▨ | ▨ | | | ▨ | ▨ | ▨ | | | ■ | ▨ | ■ | | ▨ | ▨ | | | | | ■ | E | | |
| Printed tasks | | | | | | | | | | | | | | | | | | | | | | | | |
| 6-point type | | | | | | | ▨ | | | | ■ | | | | | | | | ■ | E | | | | |
| 8- and 10-point type | | | | | | | | | | | ■ | | | | | | | | ▨ | D | | | | |
| Glossy magazines | | ■ | | | | | ▨ | | | | ■ | | ■ | | | | | | ▨ | D | | | | |
| Maps | | ■ | | | | | ▨ | | | | ■ | | ■ | | | | | | ■ | E | | | | |
| Newsprint | | ▨ | | | | | ▨ | | | | | | | | | | | | ■ | D | | | | |
| Typed originals | | | | | | | | | | | | | | | | | | | ▨ | D | | | | |
| Telephone books | | | | | | | ▨ | | | | | | ■ | | | | | | ■ | E | | | | |

# Light Sources

A wide variety of light sources are available to light schools. Light source selection critically affects building space appearance, visual performance and comfort. This section outlines the different types of sources available to the designer, describing each technology type and providing appropriate application examples.

## Incandescent and Halogen Lamps

Incandescent lamps represent the oldest of electric lighting technologies. In many older schools incandescent lamps illuminate most or all of the building spaces. The advantages of incandescent technology include point source control, high color performance, instant starting, and easy and inexpensive dimming. Disadvantages include low efficacy, short lamp life and high maintenance costs.

Incandescent sources should not be used in new buildings except in very limited and special accent lighting circumstances. Examples might include dimming applications where color performance, beam control, and/or dramatic effect is critical, such as teleconferencing rooms, theaters, and the highlighting of artwork. In most of these cases halogen sources, which offer longer life, better point source control, and crisper color performance, are superior to standard incandescent lamps.

### Fluorescent Lamps

Fluorescent lamps can and should be used to light nearly all types of school building spaces. They offer long life, high efficacy, good color performance, and low operating and maintenance costs. There are no inherent disadvantages to fluorescent technology; however, dimming fluorescent lamps requires special electronic ballasts that incur a cost premium over standard high frequency ballasts.

Fluorescent lamps and all other discharge light sources require ballasts to operate. Ballasts perform the starting function for the lamp, and they limit or regulate lamp arc current. To dim discharge lamps, special ballasts designed specifically for that function are required. Ballast selection has a significant impact on building space appearance and lighting system energy use, and should be carefully considered when designing lighting systems.

Several different types of fluorescent lamps are worth noting.

- T-12 lamps are a relatively antiquated technology that has been supplanted by higher quality products. They are still useful in some low temperature applications, such as cafeteria food storage areas.
- T-8 lamps have rapidly become the dominant lamp technology on the commercial and institutional markets. When combined with electronic ballasts, they represent a significant performance improvement over T-12 technology. Advantages include higher efficacy, more design options, better color rendition, reduced flicker and less noise. Newly available "premium" T-8 lamps offer higher color rendition, higher maintained lumens, and a 20% increase in lamp life over standard T-8s. They should be considered for most general lighting applications in schools, including classrooms, offices, multipurpose rooms and libraries.
- T-5 lamps have very similar performance to T-8 lamps, but offer a more compact lamp envelope (5/8 in. vs. 1 in. in diameter). This allows for their use in smaller profile luminaires. They are especially effective in indirect luminaires, cove lighting systems, and wall washers. T-5 luminaires should be well shielded to minimize glare. Note that T-5 lamps are NOT interchangeable with T-8 systems, and they require dedicated sockets, ballasts and luminaire housings.
- T-5 High Output (T-5HO) lamps represent an exciting development in fluorescent lamp technology. One T-5HO lamp produces nearly the equivalent maintained lumens as two standard T-8 lamps. This allows the use of fluorescent technology (and the

accompanying control and starting advantages) in some high-bay applications that previously would have required high intensity discharge (HID) sources. In addition, T-5HO luminaires with special optical components may allow a designer to increase the spacing between direct/indirect luminaire rows, as compared to a typical T-8 design. This promotes the use of fewer lamps and/or fewer luminaires, leading to reduced lighting maintenance costs. Currently T-5HO systems carry a fairly significant cost premium when compared to T-8 designs; however, prices are expected to drop as the technology matures. Due to the intense surface luminance of these lamps, they must be used in well-shielded luminaires to avoid unacceptable glare.

## Fluorescent Ballasts

Fluorescent lamps and all other discharge light sources require ballasts to operate. Ballasts perform the starting function for the lamp, and they limit or regulate lamp arc current. To dim discharge lamps, special ballasts designed specifically for that function are required. Ballast selection has a significant impact on building space appearance and lighting system energy use, and should be carefully considered when designing lighting systems.

Electronic high frequency ballasts are now standard equipment for most fluorescent sources. Ballast manufacturers are gradually phasing out the production of many older technology electromagnetic ballasts, most of which will be legislated out of existence in 2002. In addition to their efficiency advantages, electronic ballasts reduce flicker and ambient noise, and are available in a variety of ballast factor configurations, allowing the designer to "tune" light levels based on the ballast specification. Normal light output (NLO) ballasts operate lamps at about 88% of rated light output. Reduced light output ballasts (RLO) ballasts reduce light output to approximately 75% of rated light output. High light output (HLO) ballasts are also available to increase light output to as much as 120% of rated levels. In addition there is a nearly linear relationship between ballast factor and system input wattage (see Table 2).

*Table 2 – Fluorescent Lamp/Ballast Power*

| Lamps per ballast | Type of Ballast | Input power per ballast |
|---|---|---|
| (2) F32T8 | Normal (BF=0.87) | 58–60 |
| (4) F32T8 | Normal (BF =0.87) | 110–112 |
| (2) F32T8 | Low light (BF=0.78) | 50–51 |
| (4) F32T8 | Low light (BF=0.76) | 99–100 |
| (2) F32T8 | High light (BF=1.20) | 78–84 |

Consider using RLO electronic ballasts in building spaces lighted with fluorescent lamps where lower light levels will suffice. Applicable spaces might include corridors, rest rooms, storage areas and similar spaces. The reduction in light output corresponds to lower input wattage, thus reducing lighting demand and energy use.

Electronic ballasts for fluorescent lamps employ one of two methods to start the lamps. Rapid-start ballasts heat the lamp electrodes when starting the lamp, as well as while the lamp is energized. Conversely, instant-start ballasts do not apply any voltage to the lamp electrodes at any time during the operating process. Instead, the ballast initiates a relatively high voltage across the lamp to initiate the arc discharge. Instant-start ballasts are slightly more efficacious than rapid start, but they may adversely affect lamp life, particularly in applications where on-off switching cycles are short, such as in spaces with occupancy sensors.

For maximum energy performance, use instant-start ballasts in areas where the lights are unlikely to be subject to a lot of on-off cycling. In areas with more frequent switching, specify rapid-start ballasts to maximize lamp life. Newer products, known as "programmed rapid-start" ballasts, are optimized for use with occupancy sensors and in spaces where switching is more frequent.

Dimming ballasts for fluorescent lamps require an additional investment, but increase lighting system performance by optimizing space appearance, occupant satisfaction, system flexibility and energy efficiency. Lamps can be dimmed to 10%, 5%, or 1% of full light output, depending on the lamp-ballast combination. For most energy-saving applications, dimming to 5% or 10% is sufficient. However, in spaces requiring maximum dimming capability due to space needs or preferences, 1% dimming will maximize flexibility and energy savings, though at a substantial cost premium.

There are two basic types of dimming ballasts:

- 0–10 volt DC ballasts are offered by most major ballast manufacturers, and in most cases are compatible with industry standard lighting control devices, including manual dimmers, occupancy sensors, and photocell controllers.
- Line voltage dimming ballasts usually require the purchase of proprietary control gear offered by the ballast manufacturer. In some cases an additional conductor is required to handle the dimming signal.

Dimming fluorescent ballasts should be considered in all cases requiring maximum energy performance and light level flexibility. They are particularly effective in daylit classrooms, computer classrooms, audio video rooms and similar spaces.

**Compact Fluorescent Lamps**

Compact fluorescent lamps (CFLs) can be used in nearly all applications that traditionally have employed incandescent sources. CFLs offer excellent color rendition, rapid starting and dimmability. A large palette of different lamp configurations enhances design flexibility. Principal advantages of CFLs over incandescent sources include higher efficacy and longer lamp life. They can be dimmed, though dimming CFL ballasts are expensive. In colder outdoor environments, they can be slow to start and to come to full light output.

Use CFL lamps extensively in task and accent lighting applications, including wall washing, supplementary lighting for visual tasks requiring additional task illumination above ambient levels, and portable task lighting in computer environments. They are also valuable for medium to low-level general illumination in spaces such as lobbies, corridors, restrooms, storage rooms and closets. In most non-mountain California climates they are quite suitable for outdoor corridors, step lighting, and lighting over doorways. High wattage biax-type CFLs can be used for general space illumination in recessed lay-in troffers (see Luminaires section below), as well as in more decorative direct/indirect luminaires for office lobbies, libraries and other spaces requiring a more "high end" look.

### High Intensity Discharge (HID) Lamps

HID lamps provide the highest light levels of any commercially available light source in a wide variety of lamp wattages and configurations. In addition, they offer medium to high efficacy and relatively long lamp life. The principal disadvantage to HID sources is that they start slowly and take time to warm up before coming to full brilliance. This makes them difficult to use in many automatic lighting control scenarios without the use of expensive two-level switching systems. In some applications, such as warehouses and vehicle maintenance areas, this may be cost effective when evaluated from a life-cycle cost perspective, but be prepared for reduced color performance and lamp life if used with metal halide lamps. Dimming HID lamps is expensive and unreliable, and not recommended.

HID lamps are appropriate for use in exterior and high ceiling interior lighting applications, including gymnasiums, warehouses, parking lots, exterior corridors and building floodlighting. In interior applications, select metal halide HID lamps for good color appearance and rendering. Premium "pulse-start" metal halide lamps offer improved starting, color uniformity and rendition, longer lamp life and higher lumen maintenance than standard metal halide lamps. This is due primarily to advances in arc tube technology. Pulse-start lamps can often be used in place of incandescent or halogen sources in applications requiring point source drama and high color performance. High-pressure sodium HID lamps produce a golden-colored light. Their most appropriate uses are in exterior environments, or in interior applications, such as warehouses and other storage areas, when color performance is secondary to efficacy and maintenance goals.

### HID Ballasts

Metal halide and high-pressure sodium lamps also require ballasts to start the lamp and regulate electrical operation. Control of the arc current is particularly critical to the successful operation of HID sources, and ballasts are designed to perform this function within relatively close tolerances.

Pulse-start metal halide and high-pressure sodium ballasts employ an electronic ignition pulse to initiate the arc and start the lamp. In standard metal halide lamps, however, the ballast starts the lamp via a separate starting electrode within the lamp. This method of starting the lamp takes longer than the pulse-start system.

Electronic ballasts do not offer the same magnitude of energy-efficiency benefits to HID lamps as they do to fluorescents, and there is a limited selection of products on the market. The main benefit of electronic HID ballasts is more precise control of the arc's electrical characteristics. In metal halide lamps this can improve lamp color uniformity and reduce color shift.

### Light Emitting Diodes (LEDs)

LEDs are semiconductor devices that generate an intensely directional, monochromatic light. Research today is directed at producing a commercially viable white LED source. At this time, because selection is mainly limited to red, blue or green products, LED use as a light source in schools is generally limited to exit signs and other signs. The principal advantage of LEDs over other sources is their extremely long life. In addition, a two-sided LED exit sign can usually be illuminated with less than 5 watts.

LEDs are highly recommended for use in school exit signs. They offer high efficacy and very low maintenance costs when compared with either incandescent or fluorescent products, and are available in most of the popular exit sign configurations.

## Luminaires

Luminaires (light fixtures) generally consist of lamps, lamp holders or sockets, ballasts or transformers (where applicable), reflectors to direct light into the task area, and/or shielding or diffusing media to reduce glare and distribute the light uniformly. There is an enormous variety of luminaire configurations. This section briefly outlines some of the more important types for school lighting design.

### Recessed Luminaires

Recessed luminaires represent a large segment of the overall luminaire market. There are two basic variations:

- *Lay-in troffers* recess into an acoustical tile ceiling. The most common types measure 2 ft x 4 ft or 2 ft x 2 ft. With the use of a special flange, they can also be recessed into gypsum board ceilings. They typically consist of a housing, reflector, mounting hardware, lamps, ballast, and a lens or other shielding or diffusing media, such as parabolic louvers. Their primary use is as a direct general light source. They are among the least expensive of light fixtures available. Their primary advantages are their low cost and their ability to produce high levels of uniform horizontal light. They are generally less effective than other types of luminaires at producing the high wall and ceiling illumination levels that are important for visual comfort. This is particularly true of the parabolic troffer.
- *Downlights* can also be recessed into t-bar or hard ceilings. They are relatively compact luminaires used for wall washing, accent lighting, supplemental general or task illumination, as well as for lower levels of ambient illumination. Both square and round configurations are available in nominal overall diameters of 6 in., 7 in., 8 in., 10 in. and 12 in.. They use incandescent, compact fluorescent or HID sources. Specific luminaire components vary depending on application.
- *Other types:* A relatively recent addition to the recessed luminaire family is a modified version of the standard troffer that indirectly reflects light into the space. These are marketed as "indirect troffers", and their intent is to soften the distribution pattern of a direct distribution luminaire without losing the benefit of lighting uniformity. However, in many cases the surface brightness of the exposed reflector is actually higher than that of a standard troffer. Use them with caution, and don't use them in larger building spaces such as classrooms and open offices.

## Suspended Classroom Luminaires

Suspended indirect or direct/indirect luminaires are the preferred luminaires for lighting classrooms. They are also appropriate for offices, administrative areas, library reading areas and other spaces. Typically these luminaires employ T-8, T-5, or T-5HO lamps, and mount in continuous row configurations.

Some people dislike the "cloudy day" effect produced by 100% indirect luminaires, and prefer some direct illumination. However, luminaires with too much of a direct component can produce shadows, glare or reduced uniformity. This is particularly true with T-5HO lamps, which should not be used in suspended luminaires with more than 5–10% direct distribution. Fortunately, luminaire optical system options allow the designer to determine the amount of indirect and/or direct illumination.

By using the ceiling to distribute light into the room, indirect and direct/indirect fixtures efficiently produce soft, uniform illumination throughout the space. They typically require at least a 2-ft extension from a minimum ceiling height of 10 ft for acceptable uniformity and to avoid ceiling "hot spots."

High-end suspended classroom luminaires are constructed of extruded aluminum and cost significantly more; however, steel luminaires are available at prices comparable to recessed troffers, particularly when installation labor costs are factored in. Luminaires can usually be specified to include transparent dust covers, which prevent dirt and refuse (spitballs, paper airplanes, etc.) from accumulating inside the fixture, thereby blocking light and increasing required maintenance.

## Suspended High Ceiling Luminaires

Both fluorescent and HID suspended luminaires are useful for illuminating building spaces such as gymnasiums and other high-ceilinged spaces. HID luminaires can be classified as either high bay (>25 ft mounting height) or low bay, depending on the configuration. High-bay luminaires typically consist of either a spun aluminum reflector or prismatic refractor with an open or clear plastic bottom and a very direct distribution pattern. Low-bay luminaires typically employ a lens or diffuser to increase distribution uniformity. Metal halide is preferable to high-pressure sodium in gymnasiums due to its superior color performance.

Compact fluorescent high-bay luminaires are also available to light high ceiling spaces. They employ up to eight compact fluorescent lamps to approximate the light output of an HID luminaire, while allowing for additional control flexibility.

Linear hooded industrial fluorescent luminaires can be extremely effective at lighting high ceiling spaces. T-8 lamps with HLO ballasts or T-5HO lamps will produce adequate illumination for all but the highest spaces. Using fluorescent lamps allows for sophisticated control schemes and minimizes lighting maintenance costs due to long lamp life. In addition, the color performance of fluorescent is superior to that of metal halide. Be sure to use wire lamp guards for luminaires in gymnasiums or in other areas subject to damage or abuse.

## Surface-mounted Luminaires

Surface-mounted fluorescent, compact fluorescent and HID luminaires are valuable for wall and ceiling mounting situations, particularly when ceiling access is a problem. Fluorescent luminaires of this type include straight-sided "modular" fixtures that resemble recessed troffers in shielding media and optical performance, inexpensive, utility "wraparounds" for general lighting purposes; wall-mounted bathroom mirror lights; and many other configurations. Surface-mounted compact fluorescent luminaires include one-lamp, two-lamp, and three-lamp utilitarian drum lights; bathroom vanity lights; exterior wall and ceiling corridor lights; and decorative wall sconces and ceiling fixtures. Ceiling-mounted HID canopy lights can be used to light exterior corridors or gymnasiums and other high ceiling spaces, depending on configuration and lamp size.

## Specialty Luminaires

Several specialty luminaires are available for specific school lighting applications. These include specialty wall wash luminaires to illuminate blackboards, task lighting luminaires to supplement general illumination, wet location luminaires for exterior areas open to the elements, and high-abuse luminaires designed to withstand vandalism in school and other institutional environments.

Blackboard lights provide supplemental vertical illumination on the teaching wall. Specially designed recessed or surface-mounted linear fluorescent luminaires provide high levels of uniform illumination when mounted in continuous rows over the vertical surface. To minimize specular reflections from whiteboard surfaces, the aiming angle of the luminaire should not exceed 30 degrees from nadir.

Specialty task lighting luminaires are important in areas such as computer classrooms or offices where ambient illumination levels are kept relatively low. Portable or furniture-mounted task lights can provide supplemental illumination for certain paper tasks and other visual work requiring higher illumination levels. Usually these luminaires employ compact fluorescent or halogen lamps and include local switches or dimmers to allow the user some flexibility.

Wet location luminaires are required in exposed exterior locations. These luminaires carry a wet UL designation and have internal gasketing and heavy-duty fasteners. They are available in numerous configurations of enclosed fluorescent, compact fluorescent and HID luminaires. They cost more than standard luminaires.

High-abuse luminaires are recommended for areas subject to vandalism, including corridors, restrooms, exterior areas and other common areas. These fixtures typically are constructed of more robust materials than standard luminaires and usually include tamper-proof mounting hardware. They cost significantly more than standard fixtures but stand up much better to abuse.

## Exit Signs

Numerous exit sign configurations are available for schools. LED exit signs offer the best alternatives for minimizing energy use and maintenance. However, compact fluorescent exit signs may be preferable in some instances when higher surface brightness or an additional downlight component is desired. Avoid self-luminous atomic exit signs because they are difficult to dispose of, and may not provide adequate surface luminance.

# Lighting Controls

Lighting controls are critical for minimizing lighting energy use and maximizing space functionality and user satisfaction. Control techniques ranges from simple to extremely sophisticated. This section outlines lighting control hardware available for school applications, and offers some application tips for effective use of lighting controls.

## Switches

Manual switches are the simplest form of user-accessible lighting control. Minimal compliance with Title 24 requires individual manual switching for each separate building space. Bilevel switching is also required in spaces larger than 100 ft$^2$ with a connected lighting load greater than 1.0 W/ft$^2$. Additional switching requirements are triggered by daylit spaces.

Manual switches are especially valuable in daylit building spaces because they allow people to turn off electric lights when daylight is adequate. Manual switches should also be installed in spaces with occupancy sensors. This increases the energy savings of occupancy sensor controls by allowing people to turn off the lights when they are not needed.

## Occupancy Sensors

Occupancy sensors employ motion sensors to shut lights off in unoccupied spaces. The primary detection technology can be either passive infrared (PIR) or ultrasonic. Each type has advantages and disadvantages depending on the building space type, space usage, and configuration. Some sensors employ both passive infrared and either ultrasonic or microphonic detection. Sensors have adjustments to control their overall sensitivity, and to control the "time out" period between last detection and turning off the lights.

There are two basic types of occupancy sensor mounting configurations. The simplest configuration fits in a standard single gang box in place of a standard wall switch. Most of these devices also have an integral manual switch. Wall box sensors are useful in most small building spaces such as private offices, but they are inappropriate in classrooms and other large building spaces, or in areas where they cannot "see" the space occupants due to mounting location or distance.

For larger building spaces, ceiling or wall-mounted sensors provide detection of areas up to 2,000 ft$^2$. These devices require a separate relay/transformer unit or "switch pack" to power the sensor and switch the lights. It makes good sense to wire wall switches in series with the sensor to allow manual override capability in many building spaces.

Occupancy sensors are most effective in spaces that are intermittently occupied, or where the lights are likely to be left on when unoccupied. The best school applications include classrooms, private offices, restrooms and storage areas. Use occupancy sensors in combination with manual overrides whenever possible to maximize energy savings, space flexibility, and occupant satisfaction. Including manual off override to the control scheme allows the teacher to turn the lights off for video presentations or other situations requiring the lights to be off.

### Time Controls

Time controls save energy by reducing lighting time of use through preprogrammed scheduling. Time clocks comply with the Title 24 requirements for whole building shut-off in buildings greater than 5,000 ft.$^2$ Time control equipment for lighting comes in a variety of configurations with varying degrees of complexity. The simplest devices are designed to control a single electrical load, while extremely sophisticated systems typically control several lighting zones. The larger systems employ low-voltage relay switching technology, and can often link up well with energy management controllers.

Time controls make sense in many applications where a predictable schedule of operation can be defined, and where occupancy sensor automatic control is either impractical or undesirable. Candidate building spaces include classrooms, offices, library stacks (local digital time switches), auditoriums, and exteriors. Keep in mind that Title 24 requires manual override of time clock control whenever they are installed to comply with whole building shut off.

### Energy Management Systems (EMS)

Energy management systems can be configured to control lighting circuits. Typically when lighting is controlled through an EMS it is via a time clock. However, many building operators take advantage of the built-in EMS functions to monitor lighting usage on a space-by-space basis. EMS control of lighting systems may also allow building operators to shed non-essential lighting loads during peak demand periods.

### Manual Dimmers

Next to standard wall switches, manual dimmers are the simplest of lighting control devices. Manual dimmers serve two important functions. First, dimming lights reduces lighting demand and energy usage. With incandescent and halogen sources, there is the additional benefit of extended lamp life. However, more importantly, dimmers allow people to tune the lights to optimum levels for visual performance and comfort.

Consider manual dimmers (combined with dimming ballasts, where applicable) for many school building spaces, including classrooms, computer classrooms and office spaces. A/V rooms *require* manual dimming to function properly.

### Photoelectric controls

Photoelectric control systems employ a photosensor and logic controller to control lights in daylit spaces, such as classrooms and corridors. The logic controller processes a signal from the photosensor and sends a dimming or switching signal to the lighting circuit based on the monitored light level. Open-loop systems "see" only daylight, while closed-loop systems monitor both daylight and the light emitted by the luminaires they control.

Successful employment of photoelectrically controlled lighting systems requires careful design, installation, and commissioning, as well as a commitment to the long-term maintenance of the system. Without these elements, energy savings are rarely sustainable.

## General Application Notes for Lighting Controls

Lighting control strategies are most successful when people can easily understand their operating characteristics. Another critical factor is the proper commissioning of lighting control systems so that they operate according to design intent. Finally, regularly scheduled maintenance of control equipment will improve the long-term success of the system. Poorly designed, commissioned or maintained automatic lighting controls can actually increase lighting energy use, and cause user dissatisfaction.

For optimizing lighting control performance, consider the following rules of thumb when designing lighting control systems:

- Provide control interfaces that are easy to understand and operate by building users
- Always commission automatic lighting controls after installation to ensure compliance with design intent
- Involve the lighting control equipment manufacturer in the specification, installation and commissioning of lighting controls
- Include lighting control commissioning plans in bid specifications
- Provide detailed maintenance procedures for all specified controls
- Involve building users in the energy-saving process by communicating lighting control design intent

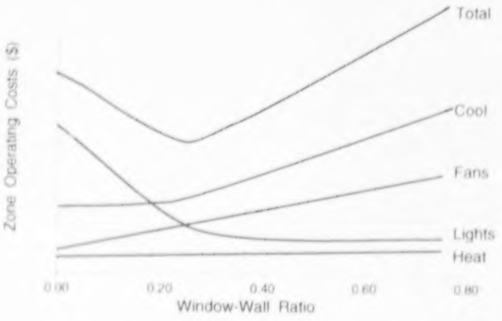
# APPENDIX F – DAYLIGHTING AND FENESTRATION DESIGN SUPPLEMENT

The Daylighting and Fenestration Design chapter of this manual provides an overview of design high performance daylighting systems for schools, as well as specific design guidelines. This supplement offers a more in-depth discussion of certain aspects of daylighting design, including:

- Optimizing Aperture Size
- Fenestration Products
- Other Design Criteria for Daylighting Systems

## Optimizing the Aperture Size

The optimum size of the daylighting aperture depends on a number of factors, including the pattern (light shelves, sawtooth roof monitor, etc.), the desired illuminance level of the school space that is being daylit, and the type of glazing material selected. Climate and internal loads (heat given off by people and equipment) are also important considerations since the optimum aperture size is the one that minimizes the total operating cost.



Note: South Orientation, Double Green Glass, Long Beach, CA

Figure 1 – Optimum Aperture Area

For a given daylighting pattern, glazing material, occupancy pattern, lighting level, electric lighting control system, and climate, the total operating costs can be calculated and plotted for various window areas, as shown in Figure 1 for a window with vertical glazing. As glazing area increases, the energy use for lighting is steadily reduced until the window area is about 25% of the exterior wall. After that, daylight saturation is achieved for much of the time, and lighting energy savings are much smaller with increased window area. However, both cooling load and fan energy increase steadily throughout the entire range of window-wall ratios. Note that cooling energy increases at a more rapid rate after daylighting saturation is achieved at a window-wall ratio of about 25%. Heating energy is relatively flat in this example, but it also increases with window-wall ratio. In cold, sunny climates, heating energy might actually decline for part of the window-wall ratio range, especially for south-facing orientations.

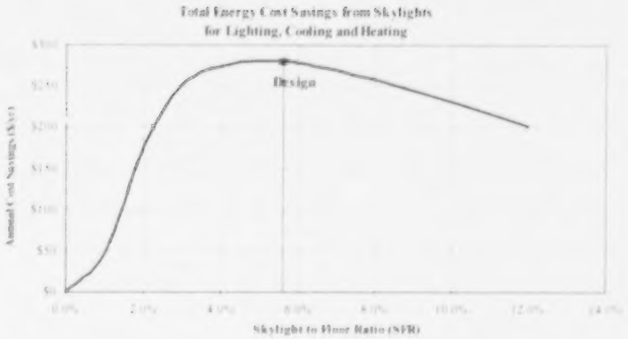


Figure 2 – Energy Cost Savings from Skylights

*SkyCalc graph shows optimum skylight to roof area ratio for classroom skylight design in Los Angeles using high transmission skylights. Results vary by skylight design and climate location.*

A similar set of graphs can be generated for skylights. Figure 2 shows the change in energy savings as skylight area becomes a larger percentage of the floor area. This graph indicates that whole building energy savings increase until the skylight area represents about 5% of the floor area and then begins to decrease, although the savings are still positive with larger areas. In general, skylights should represent about 4–8% of the floor area for good daylighting with minimal energy costs. In milder climates, larger areas generally make more economic sense. Computer tools such as SkyCalc allow quick analysis of design alternatives.

Remember that optimizing heating and cooling impacts are not the only criteria in sizing windows and skylights. Observations of classrooms have indicated that if daylight levels are high enough in the morning when school starts, then teachers are more likely to use less electric light. Minimum threshold of daylight illumination may also be appropriate for other visual and comfort reasons. Most designs are likely to strike a compromise between desired daylight levels and minimized overall energy use.

## Glazing Products

Some of the greatest glazing advances in recent years have been in the area of special low-e coatings applied to the surface of the glazing. Originally developed to lower the U-factor of double glazed windows, low-e coatings have a low "emissivity" value, meaning that they repress radiation of heat between the panes of glass. In cold weather, this saves energy by reducing heat loss from the warm inner pane to the cold outer pane of glass. It also increases thermal comfort considerably by keeping the inner pane of glass warmer, so it does not feel like a large cold surface to occupants. In hot climates, it performs the opposite function for air-conditioned spaces, keeping the "coolness" in.

*Figure 1 – Heat Transfer Through Glazing*

More important than the U-factor for many of California's milder climates, glazing should also have a low SHGC to minimize solar gains but a high VLT to maximize daylighting potential. The efficacy of fenestration is the ratio of VLT to SHGC. The higher the efficacy, the better the fenestration product is in allowing daylight and reducing solar gains. Glazing materials with a high efficacy are known as "selective" glazing materials because they selectively transmit radiation in the visible portion of the spectrum while blocking solar radiation in the ultraviolet and infrared spectra. Selective products will have a VLT to SHGC ratio > 1.3.

A high glazing efficacy is achieved through several technologies. First, many glazings are tinted by the addition of a rouge added to the silicon when the glass is manufactured. Tints such as bronze or gray are poor performers and actually reduce the glazing efficacy, while green and blue tints typically increase the efficacy. Another approach to increase efficacy is with the use of the new generation of "selective" low-e coatings that have been engineered to minimize solar gains in addition to reducing thermal losses. These selective low-e coatings (See Figure 6.) are virtually clear and colorless, but can block more heat than a heavily tinted gray glazing. However, they are relatively soft and must be located on the second or third surfaces of double glazing so that they are protected from abrasion.

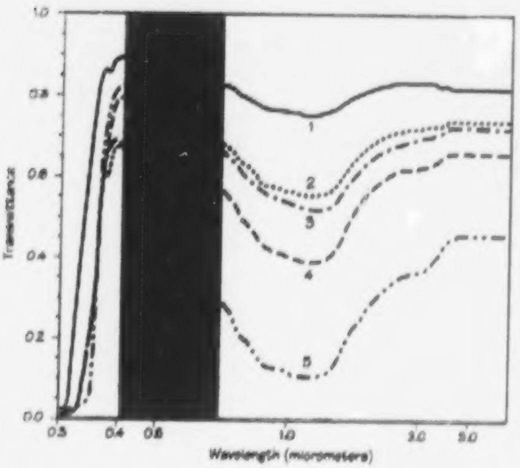


*Figure 2 – Glazing Efficacy*

Green tinted glass is a good inexpensive and efficient glazing material for California climates; in either a single or double glazing assembly. When double-glazing can be justified for thermal reasons in colder climates, then a selective low-e coating should be considered on the second or third surface. However, for passive solar designs, which require solar gain, specify the original (SHGC >.6), not selective, low-e coating.

*Table 1 – Solar Optic Properties of Vertical Glass Materials & Coatings*

| *Number of Panes* | *Tint* | *Special Coatings or Films* | *U-factor (COG)* | *Visible Light Trans. (VLT)* | *Solar Heat Gain Coefficient (SHGC)* | *Glazing Efficacy (VLT/SHGC)* |
|---|---|---|---|---|---|---|
| Single | Clear | None | 1.09 | 0.88 | 0.82 | 1.08 |
| | Green | None | 1.09 | 0.75 | 0.61 | 1.23 |
| | Bronze | None | 1.09 | 0.53 | 0.61 | 0.87 |
| | Selective tint | None | 1.11 | 0.72 | 0.52 | 1.37 |
| Double | Clear | None | 0.48 | 0.78 | 0.70 | 1.12 |
| | Green | None | 0.48 | 0.66 | 0.49 | 1.35 |
| | Bronze | None | 0.48 | 0.47 | 0.49 | 0.96 |
| | Selective tint | None | 0.48 | 0.64 | 0.40 | 1.58 |
| Double | Clear | Orig. Low-e | 0.31 | 0.73 | 0.62 | 1.18 |
| | Clear | Selective Low-e | 0.29 | 0.70 | 0.37 | 1.89 |
| | Clear | Sunbelt Low-e | | | | |
| | Selective tint | Selective Low-e | 0.29 | 0.56 | 0.27 | 2.07 |
| Triple | Clear | Mylar Film | 0.27 | 0.63 | 0.47 | 1.34 |
| | Green | Mylar Film | 0.27 | 0.55 | 0.35 | 1.57 |
| | Selective tint | Mylar Film | 0.27 | 0.51 | 0.29 | 1.76 |

Notes:
Values are for standard metal frame construction Center of Glass. Special tint glass refers to tinted products such as Azurlite or Evergreen.
N/A = Not Available

In addition to the glass types mentioned above, there is a large variety of sheet and formed plastic materials used in fenestration, especially skylights. The most common materials used are acrylic and polycarbonate plastics and fiberglass. These products may be in flat sheets, formed domes (or other shapes), or extruded channels (double or triple walled, to decrease the U-factor and provide some diffusion). Their performance specifications are similar to their glass counterparts, but unfortunately, tested values are frequently not available for commercial glazing units. All these products are susceptible to UV degradation and must have a UV inhibitor added to maintain clarity and keep them from yellowing.

Acrylic materials are cheaper than polycarbonates, but polycarbonates are stronger and more scratch resistant. Fiberglass is a highly variable material, since it is frequently not made from a uniform pre-manufactured sheet material, but is made by applying the resin and glass mixture to a form. Thus, exact thickness and composition of the material can vary along with its diffusing characteristics. Since low-e films cannot be adhered to these materials at this time, the low-e performance noted above is not available for the lower cost versions of these plastic fenestration products. Table 3 shows some generic specifications for a range of these products.

These materials may diffuse the light with either an added "white" pigment, a prismatic surface or imbedded fibers (fiberglass). While pigments can successfully diffuse the light, they inevitably also reduce the visible transmittance of the glazing, reducing overall efficiency. Prismatic and fiberglass materials diffuse the light through optics, and can maintain higher visible transmittance. There is, however, no standard language or widely available measurement that accurately describes diffusion properties. There are test standards, such as ASTM E167-96, which measure diffusion; however these results are rarely available. As a result, the specifier should describe a visual inspection procedure to evaluate samples of the glazing material or the skylight assembly for diffusion.

*Table 2 – Solar Optic Properties of Plastic Glazing Materials*

| *Material* | *Layers* | *Color* | *U-factor* | *Visible Light Trans. (VLT)* | *Solar Heat Gain Coefficient (SHGC)* | *Glazing Efficacy (VLT/SHGC)* |
|---|---|---|---|---|---|---|
| Acrylic | Single | Clear | | .92 | .77 | 1.19 |
| | | Med. White | | .42 | .33 | 1.27 |
| | | Bronze | | .27 | .46 | .59 |
| | Double | Clear | | .86 | .77 | 1.10 |
| | | Med. White | | .39 | .30 | 1.28 |
| | | Bronze | | .25 | .37 | .67 |
| Fiberglass | Single | | | | | |
| | Double | | | | | |
| | Sandwiched w/ batt insulation | White | 0.24 | .2 | .23 | .85 |
| Polycarbonate | Single | Clear | | 85 | 89 | .96 |
| | | Med. White | | .37 | .50 | .73 |
| | | Bronze | | .50 | .69 | .73 |
| | Double | Clear | | .73 | .75 | .97 |
| | | Med. White | | 32 | .43 | .74 |
| | | Bronze | | .43 | .58 | .73 |

## Links with Other High Performance Design Measures

### Interaction with HVAC

Fenestration impacts the heating and cooling loads on a school because it has a higher U-factor than other portions of the building envelope and because it has the potential to admit solar gain. The U-factor for most windows is about 1.1 for single-glazed windows and 0.4–0.6 for double-glazed windows.

Fenestration oriented toward the sun may admit large amounts of solar gain. Although this may be beneficial for passive solar designs, for most buildings, it is a cooling season liability. Excessive solar gains will overheat spaces without air conditioning and will increase energy costs for air-conditioned spaces. They will even increase the first cost of the HVAC system if a larger system is specified to handle the larger loads. Appropriate sizing of apertures and design of shading and glazing can minimize these loads for each building elevation. The building energy simulation tools mentioned in the section on Whole Building Energy Simulations above can aid in evaluating overall loads and performance.

Although many schools are not intended to operate in the summer, and so may have insignificant cooling energy use, they still should be designed to minimize solar gain. This will ensure a comfortable classrooms year round, and, should school operation plans change in the future to include summer operation, will minimize energy liabilities.

HVAC systems that incorporate ceiling ducting will also increase the required ceiling plenum and reduce the allowable window head height unless they are left exposed or the ceiling is sloped at the perimeter.

### Interaction with IAQ

Operable fenestration can also provide natural ventilation and improve indoor air quality. The benefits of natural ventilation, and fenestration design strategies to promote natural ventilation, are discussed in the Daylighting Design Criteria section of Appendix __.

## Other Design Considerations for Daylighting and Fenestration Design

Daylight apertures have impacts on building performance beyond their daylighting functions. Some of these additional impacts are discussed below.

### Natural Ventilation

Operable fenestration can provide natural ventilation and improve indoor air quality. Operable windows correlate with higher standardized test scores and are associated with an overall reduction in building energy use, even in a hot, humid climate. Operable windows may be a liability for areas with constant high exterior noise, such as near airports, or exceptionally poor outdoor air quality, such as near agricultural fields with frequent plowing and chemical use. Except for these situations, operable windows should be included in all schools (especially classrooms) and designed to provide natural cross ventilation. Location of operable apertures low in the space on the windward side and high in the space on the leeward side will provide optimum ventilation performance.

### Noise Control

Most windows and skylights allow more noise to pass through than walls or roofs do. If noise transmission is a problem, then orient fenestration away from the offending noise or use a glazing system designed to minimize transmission. Reduced noise transmission is an important side benefit to using double glazing for thermal reasons.

In order to be effective, the same acoustic treatment should be used for all glazing materials throughout a building. Noise will always travel through the weakest link in the system. Both double glazing and laminated glass (especially when the laminated pieces are of different thickness) will transmit less noise than single glazing. Use of a specialized gas between the layers of double glazing may further help to dampen noise transmission. Note that the effectiveness of each of these solutions will vary depending on the wavelength (or frequency) of the offending noise. For extreme situations, consult an acoustic engineer.

### Radiant Comfort

*Large windows can create overly cold or warm surfaces, reducing thermal comfort. High performance glazing improves thermal comfort. Double glazing improves acoustic performance. Operable windows, which allow natural ventilation, improve student performance. (Photo courtesy Barbara Erwine)*

Even when air temperatures are within a comfortable range, occupants can be cold or hot because of the surface temperature of windows and skylights. This effect is intensified if the glazing surface is large and close to the occupant. The glazing surface temperature is affected by the outdoor temperature, the number of glazing panes, frame construction and low-emissivity (low-e) coatings. In winter, students near a window wall may feel cold while others near the interior are comfortable. Turning up the thermostat to satisfy students at the perimeter will use excess energy and may make students near the interior too warm. This problem is best resolved by using high performance glazing that improves radiant comfort by reducing hot glazing surfaces (in summer) and cold glazing surfaces (in winter). See the section above on Fenestration Products for recommendations on high performance glazing to increase radiant comfort.

### Safety and Security Issues

Fenestration poses safety and security liabilities both because it's breakable and because it allows views into areas that may contain valuables. These increase the risk of vandalism, and potential injury from shattering of glass or accidental falls through unprotected openings (especially skylights).

On the other hand, windows, especially can provide many important safety features for schools. Clear view glass allows supervision between the inside and outside of buildings. It's easy to spot mischief occurring inside a classroom if there's an easy view in from the outside. Operable windows can also provide a safety advantage as a secondary means of egress during any kind of emergency, or for immediate emergency ventilation in case of a chemical spill.

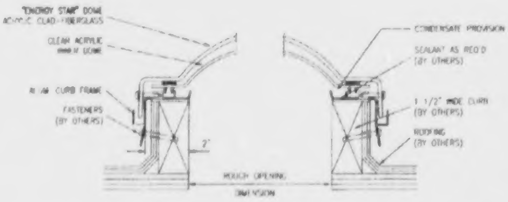
Minimize vulnerability to vandalism by using interior blinds or drapes to shield interior contents from view when the space is not occupied. Making windows or skylights easily observed from the street, or designing the building so that fenestration is difficult to access, can also help reduce vandalism. Some school districts have found that flat roofs tempt children to climb and play on them after hours, while sloped roofs substantially reduce this problem.

Minimize the risk of injury from breakage by carefully selecting the glazing materials, minimizing access to rooftops with toplighting schemes, and providing gratings to prevent falls through rooftop openings. Glazing materials that resist breakage are both safer and less susceptible to vandalism. Tempering glass quadruples its strength, and changes its breakage pattern from large shards to small "pebbles." Laminated or wired glass keeps glazing intact even when it is broken, minimizing injuries. Some form of safety glass is required for all glass within 18 in. of the floor or associated with an adjacent doorway. Underwriters Lab (UL) Standard 972 covers the strength of the glazing in resisting the efforts of burglars while ASTM Standard F588 reports how well the frame holds up to forced entry.

Most codes require that skylights be designed to withstand a fall from a 300-pound person. Use of laminated or wired glass, fiberglass, or polycarbonate rather than regular glass or acrylic plastics increases strength and eliminates shards on breakage. Most falls through skylights seem to be from people backing into them inadvertently. Use of high curbs or weight-bearing louvers or bars within the skylight well can reduce injury falls through skylights.

### Air and Water Leakage

Windows and skylights represent penetrations through the building's weather-tight skin, making it vulnerable to air and water leakage. Air infiltration can cause uncomfortable drafts and increased HVAC energy costs. Water leakage can cause damage to building contents, such as rugs, furniture and equipment. It can also create structural damage and high moisture conditions, promoting the growth of mold and contributing to sick building syndrome.



*Skylight detailing should include careful attention to flashing and condensation control.(Graphic courtesy Bristolite Skylights)*

Leakage is affected both by the construction details (the "tightness" of the seal between the fenestration and the wall or roof rough opening) and, for operable apertures, by the quality of the seals within the window or skylight unit itself. Both windows and skylights need to be properly flashed and sealed to eliminate air and water leakage problems. Skylights should sit on raised curbs, flashed like any other roof penetration. Molded plastic skylights have the advantage over glass assemblages of creating a continuous waterproof surface that is not dependent on sealants.

### Condensation

Since windows and skylights usually have higher U-factors than walls and ceilings, in winter the interior surface of the glass will be colder than the walls and ceilings. This temperature difference makes them a prime target for condensation, which occurs when warm moist air comes in contact with a cooler surface. The colder the interior surface of the glass or frame, the more likely water will condense. Because of this, single-pane glass and simple metal frames without a thermal break are especially prone to condensation. Condensation can also occur between the panes of a double-glazed window. This indicates that the seal that holds the panes together has failed. The glass often becomes cloudy, a signal that it needs to be replaced.

Small amounts of condensation on very cold days are not a major problem, but larger amounts over a long period of time can cause mold, cosmetic damage to paints and finishes and even structural damage to the wall or roof. Condensation dripping from a skylight is very often mistaken for a leak. To minimize condensation, select windows and skylights with a low overall U-factor, use low-conduction vinyl, wood or thermally broken aluminum frames, and make sure the frame is designed with weep holes to collect and redirect any moisture that accumulates. Skylights should all have a small condensation "gutter" designed to collect any condensation at night and allow it to re-evaporate during the day.

### Replacement

Windows and skylights in schools are vulnerable to breakage, so the cost and ease of glazing replacement is important. Using readily available glazing sizes, tints and coatings allows the easiest replacement options. Standardized sizing may be especially important for double-glazed units, which must be constructed as a unit and cannot be "cut to size." When replacing tinted or coated glazing, ensure that the same tint is being used and that the coating is on the same glazing surface. Although there is not a large energy penalty for switching the coating surface (say from the outer pane to the inner pane), the exterior appearance of the glazed unit as compared to others in the building may change noticeably.

Window seals in double-glazed units should carry a warranty; check to see if it is in effect if you have a seal failure. The retrofitting of a tinted film onto a window may add stresses to the glazing and will probably void the warranty.

### Maintenance

A window or skylight will deliver less light to a space if it is dirty. Under normal conditions, the accumulation of dirt can reduce the visible light transmission of vertical glass by 10% and horizontal glazing by up to 30%. All glazing should be cleaned on a regular schedule. Wash windows, and hose down skylights occasionally during dry dusty weather. High windows and skylights may also attract spider webs, which should be removed occasionally. When designing windows and skylights, consider the access to the glazing for cleaning, and the ease and cost of cleaning shading and reflecting devices. When light shelves and louvers are placed in front of glazing, accommodation must be made to clean the glass above or behind them.

**Fire Resistance**

The size of openings for windows or skylights, and the type of glazing allowed, may be restricted by code in a fire-rated construction. Many plastic glazing materials for skylights are combustible and their use is allowed with area limitations and spacing requirements. The use of sprinklers affects these parameters, as does the type of glazing material used. Placement of light shelves or diffusers should be coordinated to avoid interfering with sprinkler performance. Skylights can reduce fire spread by functioning as a smoke hatch which pops opens on a fusible link

# Volume III – Criteria

## High Performance Schools Best Practices Manual

Version 1.0
November 1, 2001

A Project of:

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# CHPS Criteria

The CHPS Criteria explicitly defines a high performance school. The criteria are most useful as a goal-setting and planning tool. Districts can use it to simply and clearly communicate their design goals. At the same time, the criteria's flexibility allows designers to deliver a CHPS school while managing the regional, district, and site-specific constraints of the school design.

## Eligibility Levels and Documentation

The criteria are flexible and address all aspects of high performance schools such as energy efficiency, water efficiency, site planning, materials and indoor environmental quality. In each area, the system is composed of both prerequisites and optional credits. Points are assigned to each credit. To be eligible, a school must meet all of the prerequisites and earn at least 28 points (at least two points must be from the Energy category). The more credits a building earns, the better it is, but the CHPS criteria are a pass/fail system.

As documentation, design teams must complete a report that identifies with a brief narrative the approach used to earn each point. Each design team or building owner will document compliance with the criteria through a process of self-evaluation. Documentation reports must be sent to CHPS. CHPS will make spot checks of documentation reports, but not check every one. However, CHPS stakeholders or other government agencies may sponsor programs where meeting these criteria is required for participation. In these cases, the program administrators may require that documentation be submitted for a thorough review. Example programs include financial incentives (such as Savings By Design), accelerated plan review, and/or bonus points for state funding.

A Criteria Scorecard has been included at the end of this document. The scorecard summarizes the requirements and applicable points for each credit.

## CHPS and LEED™

The CHPS Criteria is similar to the US Green Building Council's (USGBC) LEED™ 2.0 Rating System. However, no interchangeability between the two systems is expressed or implied. A school qualifying for CHPS may contain many of the elements needed for LEED™ certification, but there is *no interchangeability* between the two systems. Schools qualifying for CHPS may or may not qualify for LEED and vice versa. Teams wishing to pursue a LEED™ rating must do so independently. However, the USGBC has developed excellent support materials, which are referenced by CHPS. In particular, the LEED™ 2.0 Reference Manual is referenced as a resource in a number of CHPS Criteria Credits. See the USGBC's web site at http://www.usgbc.org for more information on how to join the organization and obtain the referenced materials.

## Priorities

Sustainability and high performance are broad topics. The CHPS Criteria span a wide variety of areas, from site planning and energy use, to material specifications and district resolutions. The prerequisites in the criteria are typically design issues required by state law. However, the design must move beyond the prerequisites to ensure that the CHPS school is healthy, operates efficiently, increases student productivity, and reduces environmental impact. Listed below are the design areas and credits that are recommended by CHPS to maximize the performance of the school.

- **Daylighting**. Quality daylighting designs have been proven to improve student productivity. When integrated properly with the electric lighting system, daylighting saves significant amounts of energy.
  *See IEQ Credit 1: Daylighting in Classrooms (1-4 points)*
- **Energy Efficiency**. Energy Efficiency should be a cornerstone of the CHPS school to reduce operational expenses, conserve natural resources, and reduce local and global pollution.
  *Energy Credit 1: Superior Energy Performance (2-10 points)*
  *Energy Credit 2: Natural Ventilation (1-4 points)*
- **Indoor Air Quality.** Schools must protect student health, and good indoor air quality is essential for healthy schools. Because a wide variety of design issues affect indoor air, each of the credits below must be addressed to protect indoor air quality.
  *IEQ Credit 2: Low-Emitting Materials (1-4 points)*
  *IEQ Credit 3: Pollutant Source Control (1-3 points)*
  *IEQ Credit 4: Construction IAQ Management Plan (1-2 points)*
- **Maintenance.** Without regular preventative maintenance over the lifetime of the building, a school will not perform at the level it was designed. Inadequate maintenance can cause a litany of problems from poor indoor air quality and increased energy expenses, to visually, thermally, and acoustically inadequate teaching

environments. The costs of fixing these problems often dwarf the investments to prevent them.
*District Credit 3: Maintenance Plan (1-2 points)*

- **Commissioning and Training.** All schools should be commissioned to ensure that the design meets the expectations of the district, and that the school is built as it was designed. Modern schools are complex buildings. Commissioning ensures that all building systems are working properly, and that the school staff knows how to operate and maintain them.
  *Energy Credit 4: Commissioning (2-3 points)*
- **Acoustics.** If not controlled to appropriate levels, noise from loud ventilation systems, outdoor sources, and neighboring rooms can significantly impede communication between teachers and students. Young learners, students with hearing difficulties, and those learning English as a second language are particularly vulnerable. Classrooms should be designed to be accessible for all students.
  *IEQ Credit 5: Improved Acoustical Performance (2 points)*
- **Sustainable Materials.** Hidden within all materials are the resources, energy, chemicals, and environmental damage involved in their production. More sustainable alternatives exist and should be used as much as possible.
  *Materials Credit 4: Recycled Content (1-2 points)*
  *Materials Credit 6: Certified Wood (1 point)*
- **Waste Reduction.** It is now possible to recycle, compost, or salvage a majority of construction and demolition waste instead of disposing it in landfills.
  *Materials Credit 1: Site Waste Management (1-2 points)*

# CRITERIA OVERVIEW

| Category | Group | Credit Name | | Points | Page |
|---|---|---|---|---|---|
| **Site**<br>**14 points** | Site Selection | Prereq 1 | Code Compliance | R | 6 |
| | | Credit 1 | Sustainable Site Selection | 1-6 | 7 |
| | Transportation | Credit 2 | Transportation | 1-3 | 9 |
| | Stormwater Management | Prereq 2 | Construction Erosion | R | 10 |
| | | Credit 3 | Post-construction Management | 1-2 | 11 |
| | Outdoor Surfaces | Credit 4 | Design to Reduce Heat Islands | 1-2 | 12 |
| | Outdoor Lighting | Credit 5 | Light Pollution Reduction | 1 | 13 |
| **Water**<br>**5 points** | Outdoor Systems | Prereq 1 | Create Water Use Budget | R | 14 |
| | | Credit 1 | Reduce Potable Water for Landscaping | 1-2 | 16 |
| | Indoor Systems | Credit 2 | Water Use Reduction | 1-3 | 17 |
| **Energy**<br>**24 points** | Energy Efficiency | Prereq 1 | Minimum Energy Performance | R | 20 |
| | | **Credit 1** | **Superior Energy Performance** | **2-10** | 22 |
| | | **Credit 2** | **Natural Ventilation** | **1-4** | 24 |
| | Alternative Energy Sources | Credit 3 | Renewable Energy | 2-6 | 25 |
| | Commissioning and Training | Prereq 2 | System Testing & Training | R | 27 |
| | | **Credit 4** | **Commissioning** | **2-3** | 29 |
| | | Credit 5 | Energy Management Systems | 1 | 31 |
| **Materials**<br>**11 points** | Waste Reduction and Efficient Material Use | Prereq 1 | Storage and Collection of Recyclables | R | 32 |
| | | **Credit 1** | **Site Waste Management** | **1-2** | 33 |
| | | Credit 2 | Building Reuse | 1-3 | 34 |
| | | Credit 3 | Resource Reuse | 1-2 | 35 |
| | Sustainable Materials | **Credit 4** | **Recycled Content** | **1-2** | 36 |
| | | Credit 5 | Rapidly Renewable Materials | 1 | 39 |
| | | **Credit 6** | **Certified Wood** | **1** | 40 |
| **Indoor Environmental Quality**<br>**17 points** | Daylighting | **Credit 1** | **Daylighting in Classrooms** | **1-4** | 41 |
| | Indoor Air Quality | Prereq 1 | Minimum Requirements | R | 42 |
| | | **Credit 2** | **Low-Emitting Materials** | **1-4** | 44 |
| | | **Credit 3** | **Pollutant Source Control** | **1-3** | 45 |
| | | **Credit 4** | **Construction IAQ Management Plan** | **1-2** | 46 |
| | Acoustics | Prereq 2 | Minimum Acoustic Performance | R | 47 |
| | | **Credit 5** | **Improved Acoustical Performance** | **1-2** | 48 |
| | Thermal Comfort | Prereq 3 | ASHRAE 55 Code Compliance | R | 49 |
| | | Credit 6 | Controllability of Systems | 1-2 | 50 |
| **District Resolutions**<br>**10 points** | High Performance Policies | Credit 1 | District Resolutions | 1 | 51 |
| | Indoor Air Quality | Credit 2 | IAQ Management Plan | 1 | 52 |
| | Maintenance | **Credit 3** | **Maintenance Plan** | **1-2** | 53 |
| | Energy | Credit 4 | Equipment Performance | 1-2 | 54 |
| | | Credit 5 | Green Power | 2 | 55 |
| | Transportation | Credit 6 | Buses and Alternative Fueled Vehicles | 1-2 | 56 |

**Credits in bold font** = CHPS-recommended credits

**Total Points** 81

**Minimum required for CHPS School** (Two points must be in Energy category) **28**

# SITE

## Site Selection

Purpose: Choose sites that protect students and staff from outdoor pollution and minimally impact the environment. Channel development to centrally located areas, with existing infrastructure, to protect greenfields, minimize transportation requirements, and preserve habitat and natural resources.

**Site Prerequisite 1: Code Compliance**

| | |
|---|---|
| *Required* | P1.1. Title 5 compliance. Comply with all siting and environmental impact study requirements of the School Facilities Planning Division as defined in Title 5, Division 1, Chapter 13 of the California Code of Regulations, including:<br>▪ DTSC site review for hazardous agents, including industrial, agricultural, and naturally occurring pollutants such as asbestos and heavy metals.<br>▪ The air pollution control district or air quality management district having jurisdiction in the area must identify nearby facilities which might reasonably be anticipated to emit hazardous air emissions, or to handle hazardous or acutely hazardous materials, substances, or waste and determine that they will not adversely affect student, staff, or teacher health.<br>▪ All other siting requirements, including separation from power-line easements, railroad tracks, hazardous pipelines, adverse levels of traffic noise, and avoiding construction on active earthquake faults or fault traces. |

Protecting student health is the most important issue during site selection. The state of California's Title 5 siting and environmental impact study requirements were created to eliminate sites containing pollutants known to be hazardous to student and staff health. A variety of factors, from hazardous materials in the soil to airborne pollutants from nearby sources, are included in the site review process.

All schools receiving state funding are required by law to follow the Title 5 requirements. Under the CHPS criteria, privately funded schools must also engage the SFPD and DTSC to validate that their site complies with the Title 5 requirements.

**Resources**

California Department of Education, School Facilities Planning Division. School Site Selection and Approval Guide. Available from http://www.cde.ca.gov/facilities/

## Site Credit 1: Sustainable Site Selection

| | |
|---|---|
| 1 point | 1.1. Do not develop buildings on portions of sites that meet any one of the following criteria:<br>▪ Important farmland as defined by the US Department of Agriculture.<br>▪ Land whose elevation is lower than five feet above the elevation of the 100-year flood as defined by FEMA.<br>▪ Land that provides habitat for any species on the federal or state threatened or endangered list.<br>▪ Within 100 feet of any wetland as defined by 40 CFR, Parts 230-233 and Part 22, ***OR*** as defined by local or state rule or law, whichever is more stringent.<br>▪ Land which prior to acquisition for the project was public parkland, unless land of equal or greater value as parkland is accepted in trade by the public landowner. (Park Authority projects and joint use arrangements with parkland are exempt.) |
| 1 point | 1.2. Do not build on greenfields. Greenfields are defined as those sites that have not been previously developed, or have been restored to agricultural, forestry, or park use. |
| 1 point | 1.3. Centrally located sites. Create centrally located sites in which 50% of students are located within the distances below:<br>▪ Elementary: 1 mile.<br>▪ Middle School: 2 miles.<br>▪ High School: 4 miles. |
| 1 point | 1.4. Joint use of facilities. Dedicate part of the school building for use by community or other appropriate organizations. |
| 1 point | 1.5. Joint use of parks. Share park or recreation space with local park boards or other organizations. |
| 1 point | 1.6. Reduced footprint. Increase the Floor Area Ratio (FAR) of the school to be at least 1.2 to reduce the development footprint and preserve openspace. The FAR is the quotient of a building's total square footage and its footprint. |

A district faces many issues during site selection. Cost, student demographics, and environmental concerns all influence when sites are acquired and how the district uses them. The site is a crucial element in determining the overall sustainability of the school design. Sites are sometimes purchased years in advance, and some of these credits may be out of the control of the districts and/or designers at the time the school is being built. However, districts that are considering multiple sites can substantially lower the environmental impact of the school by choosing centrally located sites, sharing parks or facilities with community organizations, preserving openspace, and protecting environmentally sensitive areas.

Credit 1.1. Environmentally sensitive or important spaces should be avoided.

> **Important Soils:** The Natural Resources Conservation Services division of the Department of Agriculture maintains the definitions and soil surveys that designate areas as "important farmland". Lists of Prime and Statewide Important Farmland Soils are maintained for each soil survey area and may be obtained from the Field Office Technical Guide (FOTG) located in each

NRCS field office. County and state offices of the NRCS keep maps showing the status of maps within their jurisdiction. County offices can be located at http://offices.usda.gov/scripts/ndISAPI.dll/oip_public/USA_map

**100-Year Flood Plains:** California is in FEMA's region IX (http://www.fema.gov/Reg-IX/index.htm). To find a map showing the 100-year flood elevations, contact your community representative on the Region IX Community Status List (http://www.fema.gov/Reg-IX/r9_nfip.htm), or call 877-336-2627 to talk to a map specialist. Unofficial maps by ESRI are available online at http://www.geographynetwork.com.

**Wetlands:** The term wetlands is defined in Title 40 as "those areas that are inundated or saturated by surface or ground water at a frequency and duration sufficient to support, and that under normal circumstances do support, a prevalence of vegetation typically adapted for life in saturated soil conditions. Wetlands generally include swamps, marshes, bogs and similar areas." [Source: CFR: Title 40. 330.4]. Any coastal development is regulated by the California Coastal Commission in parallel with the U.S. Army Corps of Engineers and the California Regional Water Quality Control Board. In addition, joint consultation that includes the California Dept of Fish and Game is necessary for any projects in or adjacent to any waterway, tidal creek, wetland, or seasonal stream.

Credit 1.2. During the site selection process, use previously developed sites instead of greenfields. Urban redevelopment reduces environmental impacts by utilizing established infrastructure and preserving the openspace of undeveloped lands. If the site already contains a building, additional points may be earned with Materials Credit 2: Building Reuse.

Credit 1.3. Over the lifetime of the building, schools and parents invest significant amounts of time, energy, and money transporting students to and from school. Cars driven by parents, guardians, or the students themselves are the largest resource users and sources of transportation-related pollution. Centrally located sites allow more students to walk or bike to school, while reducing the distance cars must travel. To earn this point, calculations must be based on the estimated school population when the school opens. Additional transportation-related points are covered in Site Credit 2: Alternative Transportation.

Credits 1.4 and 1.5. Joint use of facilities and parks is a growing trend across the country and state. Schools are being integrated with a variety of organizations, from laundromats and coffee shops to police stations and park districts. Joint use can have a variety of benefits, including increasing campus security, improving community integration, and reducing site acquisition and construction costs.

Credit 1.6. Building multi-story schools reduces the amount of land used in construction. Said another way, achieving a FAR of 1.2 requires at least 20% of a school's square footage to be on a second floor.

# Transportation

Purpose: Reduce pollution and land development impacts from automobile use.

**Site Credit 2: Transportation**

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|---|---|
| 1 point | 2.1. Public Transportation. Locate building within 1/4 mile of a commuter rail, light rail or subway station, or within 1/8 mile of one or more bus lines. |
| 1 point | 2.2. Bicycles. Provide suitable means for securing bicycles for 15% or more of building occupants; ***AND*** provide bike lanes and sidewalks that extend at least to the end of the school zone. |
| 1 point | 2.3. Minimize Parking. Provide preferred parking totaling 5% of total parking spaces for carpools or vanpools and size parking capacity not to exceed<br>High schools: 2.25 spaces per classroom plus parking for 20% of students<br>Elementary and Middle: Three spaces per classroom<br>***OR***, add no new parking for rehabilitation projects and provide preferred parking totaling 5% of total parking spaces for carpools or vanpools. |

The energy-use and pollution associated with transportation often dwarfs the total lifetime energy used by the school itself. Locating the site close to public transportation, creating bike facilities and safe access, and offering bus service, all reduce the automobile-related pollution.

Credit 2.1. When available, public transportation is a very efficient method of transportation. Some school districts offer reduced or subsidized fares for students and staff using public transportation. If sufficient capacity exists, schools can use public transportation to replace district provided bus service. Schools located near high traffic areas must ensure safe student access. In addition, all transportation-related pollution must be considered when investigating site air quality and potential for natural ventilation.

Credit 2.2. Bicycles are a popular and pollution-free form of transportation. To protect pedestrians and bicyclists, bike lanes and sidewalks must extend to the end of the school zone.

Credit 2.3. Excess parking spaces encourage increased automobile use, contribute to urban heat island effects, and can increase pollution from stormwater runoff. Design parking so as not to exceed listed amounts and include clearly marked, preferred parking areas for carpools.

**Resources**

CHPS Best Practices Manual, Volume II: Guideline SP3: Safe and Energy Efficient Transportation.

LEED™ Reference Guide: Site Credit 4.

# Stormwater Management

Purpose: Manage stormwater during and after construction to control erosion and runoff, reducing the negative impacts on water and air quality.

**Site Prerequisite 2: Construction Erosion and Sedimentation Control**

| | |
|---|---|
| *Required* | P2.1. Design to a site sediment and erosion control plan that follows the best management practices outlined by the state Water Resources Control Board (WRCB) to comply with the Stormwater Construction Activities General Permit. The plan shall meet the following objectives:<br>▪ Prevent loss of soil during construction by storm water runoff and/or wind erosion, including protecting topsoil by stockpiling for reuse.<br>▪ Prevent sedimentation of storm sewer or receiving streams and/or air pollution with dust and particulate matter. |

The state WRCB is responsible for administering water-related construction permit activities. Construction projects must file a permit and develop a Stormwater Pollution Prevention Plan (SWPPP) to comply.

Individual county zoning ordinances may further delimit the Development Standards for Wetland Habitats. At the same time, any projects that result in discharge of water into a wetland require a permit from the California Regional Water Quality Control Board. Note that each local zoning ordinance may give exception to that requirement for a particular waterway.

A variety of best practices address this prerequisite, including:

| | |
|---|---|
| Runoff Control | **Minimize clearing:** land grading, permanent diversions, preserving natural vegetation.<br>**Stabilize drainage ways:** check dams, filter berms, grass-lined channel, riprap. |
| Erosion Control | **Stabilize exposed soils:** chemical stabilization, mulching, permanent seeding, sodding, soil roughening.<br>**Protect steep slopes:** geotextiles, gradient terraces, soil retention, temporary slope drain.<br>**Protect waterways:** temporary stream crossings, vegetated buffer.<br>**Phase construction:** construction sequencing, dust control. |
| Sediment Control | **Install perimeter controls:** temporary diversion dikes, wind fences and sand fences, brush barrier, silt fence.<br>**Install sediment-trapping devices:** sediment basins and rock dams, sediment filters and sediment chambers, sediment trap.<br>**Storm drain inlet protection.** |

**Resources**

CHPS Best Practices Manual, Volume II: Guideline GC4: Site Protection During Construction.

LEED™ Reference Guide: Site Prerequisite 1 Erosion and Sedimentation Control.

California Best Practices Handbooks from WRCB: http://www.swrcb.ca.gov/stormwtr/bmp.pdf.

EPA Storm Water Management for Construction Activities, EPA Document No. EPA-833-R-92-001.

EPA On-line Best Practices Information: http://www.tetratech-test.com/bmpmanual/htmfolder/menu.htm.

California WRCB: http://www.swrcb.ca.gov/stormwtr/index.html.

**Site Credit 3: Post-construction Stormwater Management**

| | |
|---|---|
| 1 point | 3.1. Limit stormwater runoff. No net increase in the rate or quantity of stormwater runoff shall occur from existing to developed conditions.<br>*OR* if existing imperviousness is greater than 50%, implement a stormwater management plan that results in a 25% decrease in the rate and quantity of stormwater runoff. |
| 1 point | 3.2. Treat runoff. Install treatment systems designed to remove 80% of the average annual post-development total suspended solids (TSS), and 40% of the average annual post-development total phosphorous (TP), by implementing best management practices outlined by Regional Water Resources Control Boards or in EPA's Guidance Specifying Management Measures for Sources of Nonpoint Pollution in Coastal Waters (EPA 840-B-92- 002 1/93). |

Stormwater runoff is precipitation that flows over surfaces on the site and enters either the sewage system or receiving waters. Stormwater carries sediment and pollutants from the site into the sewage system and/or local bodies of water. In addition, the cumulative runoff throughout the local area requires significant investments in municipal infrastructure to handle peak runoff loads.

Post-construction stormwater management is not covered under the Stormwater Pollution Prevention Plan. Post-construction stormwater management is regulated by the Regional Water Resources Control Boards with Standard Urban Stormwater Mitigation Plans (SUSMP) Region 4 (LA), Region 9 (San Diego). Some local jurisdictions, such as Alameda's Countywide Clean Water Program, have other stormwater control plans.

Credit 3.1. Reducing the amount of runoff is the most effective way to minimize its negative impacts. Many strategies exist to limit stormwater runoff:

- Significantly reduce impervious surfaces, maximize on-site stormwater infiltration, and retain pervious and vegetated areas.
- Capture rainwater from impervious areas of the building for groundwater recharge or reuse within the building.
- Use green/vegetated roofs.

Credit 3.2. Total suspended solids (TSS) are particles that are too small or light to be removed from stormwater by gravity settling alone, and must typically be removed with filtration methods. Total phosphorous (TP) consists of organically bound phosphates, poly-phosphates, and orthophosphates in stormwater, and usually originate from fertilizers. Common treatment systems include infiltration basins and trenches, porous pavement, vegetated filter strips, grassy swales, filtration basins, and constructed wetlands.

**Resources:**

CHPS Best Practices Manual, Volume II: Guideline SP11: Stormwater Management and Drainage Materials.

LEED™ Reference Guide: Site Credit 6: Stormwater Management.

EPA On-line Best Practices information: http://www.tetratech-test.com/bmpmanual/htmfolder/menu.htm.

LA Stormwater Management Division: http://www.lacity.org/san/swmd/.

Regional California Water Resources Control Boards: http://www.swrcb.ca.gov/regions.html.

# Outdoor Surfaces

Purpose: Reduce heat islands to minimize impact on microclimate, and human and wildlife habitat.

**Site Credit 4: Landscape and Exterior Design to Reduce Heat Islands**

| | |
|---|---|
| 1 point | 4.1. Landscaping Issues. Provide shade (within five years) on at least 30% of non-roof, impervious surfaces on the site, including parking lots, walkways, plazas, etc.<br>*OR* use light-colored/ high-albedo materials (reflectance of at least 0.3) for 30% of the site's non-roof, impervious surfaces.<br>*OR* use an open-grid pavement system (net impervious area of LESS than 50%) for a minimum of 50% of the parking lot area. |
| 1 point | 4.2. Cool Roofs. Use ENERGY STAR® roof-compliant roofing, with an initial reflectance of at least 0.7 and initial emmissivity of at least 0.75 for a minimum of 75% of the roof surface.<br>*OR* install a "green" (vegetated) roof for at least 50% of the roof area. |

Credit 4.1. Employ design strategies, materials, and landscaping designs that reduce heat absorption of exterior materials. Note albedo/reflectance requirements in the drawings and specifications. Provide shade using native or climate-tolerant trees and large shrubs, vegetated trellises, or other exterior structures supporting vegetation. Substitute vegetated surfaces for hard surfaces. Explore elimination of blacktop and the use of new coatings and integral colorants for asphalt to achieve light colored surfaces.

Credit 4.2. Cool roofs can significantly reduce school cooling loads and urban heat island effects by reflecting the sun's energy, instead of absorbing, retaining, and radiating it into the occupied spaces below. With cool roofs, both the reflectivity and emissivity are important. Solar reflectance is the ratio of the electromagnetic energy reflected by a surface to the total amount incident upon it. A solar reflectance of 0.0 means all the solar energy hitting the surface is absorbed and none is reflected. Emissivity is the ability of a material to shed infrared radiation. In other words, surfaces with high emissivities lower their surface temperatures by shedding infrared radiation. Bare metals, for example, have low emissivities and stay hotter for longer periods than materials with high emissivity. The EPA's ENERGY STAR program includes a database of high-reflectance roofing materials. To ensure high emmissivity, do not use bare metal roofing products.

**Resources**

CHPS Best Practices Manual, Volume II: SP2: Landscaping to Provide Shade to Buildings and Paved Areas; SP5: Impervious Surfaces; IN3: Cool Roofs.

LEED™ Reference Guide: Credit 7: Landscape and Exterior Design to Reduce Heat Islands.

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# Outdoor Lighting

Purpose: Eliminate light trespass from the building site, improve night sky access, and reduce development impact on nocturnal environments.

**Site Credit 5: Light Pollution Reduction**

| | |
|---|---|
| 1 point | 5.1. Do not exceed Illuminating Engineering Society of North America (IESNA) footcandle level requirements as stated in the IESNA RP-33 Recommended Practice for Exterior Environmental Lighting or applicable sections of the IESNA Lighting Handbook, Ninth Edition; ***AND*** design interior and exterior lighting (excluding sports fields) such that zero direct-beam illumination leaves the building site. |

Consult IESNA Recommended Practice Manual: Lighting for Exterior Environments for CIE zone and pre- and post-curfew hour descriptions and associated ambient lighting level requirements. Ambient lighting for pre-curfew hours for CIE zones range between 0.01 footcandles for areas with dark landscapes such as parks, rural, and residential areas, and 1.5 footcandles for areas with high ambient brightness such as urban areas with high levels of nighttime activity. Design site lighting and select lighting styles and technologies to have minimal impact off-site and minimal contribution to sky glow. Minimize lighting of architectural and landscape features.

**Resources**

CHPS Best Practices Manual, Volume II: EL11: Outdoor Lighting.

LEED™ Reference Guide: Site Credit 8: Light Pollution Reduction.

The International Dark Sky Association: http://www.darksky.org/ida/index.html. The California Chapter (www.skykeepers.org) maintains state-focused information. The International Dark Sky Association Lighting Handbook is available on line at http://www.nofs.navy.mil/about_NOFS/staff/cbl/LC_Handbook.html

# WATER

## Outdoor Systems

Purpose: Limit excess water use for landscaping and ornamentation.

### Water Prerequisite 1: Create Water Use Budget

| | |
|---|---|
| *Required* | P1.1. Design landscape and ornamental water use budget to conform to local Water Efficient Landscape Ordinance. If no local ordinance is applicable, then use the landscape and ornamental budget outlined by the California Department of Water Resources. |

California's Model Water Efficient Landscape Ordinance requires that landscapes be given a water budget or "water allowance." A water budget is usually expressed in terms of a percentage of amount of water that evaporates from vegetation and from the underlying soil (reference evapotranspiration) for the size of the area permitted to be landscaped. Local governments may have a different ordinance from the state model.

The California Model Landscape Ordinance requires that estimated applied water use cannot exceed the Maximum Applied Water Allowance. Maximum Applied Water Allowance means, for design purposes, the upper limit of annual applied water for the established landscaped area as specified by the equation below. It is based upon the area's reference evapotranspiration, the ET Adjustment Factor, and the size of the landscaped area. Estimated applied water use may be the sum of the water recommended through the irrigation schedule.

A project's Maximum Applied Water Allowance can be calculated using the following formula:

$$MAWA = (ETo)(0.8)(LA)(0.62)$$

where:

MAWA = Maximum Applied Water Allowance (gallons per year).

ETo = Reference Evapotranspiration (inches per year). Evapotranspiration means the quantity of water evaporated from adjacent soil surfaces and transpired by plants during a specific time. California has a directory of evapotranspiration tables from around the state. See the Resources section of this guideline.

0.8 = ET Adjustment Factor. This factor, when applied to evapotranspiration, adjusts for plant factors and irrigation efficiency, two major influences upon the amount of water that needs to be applied to the landscape.

LA = Landscaped Area ($ft^2$).

0.62 = Conversion Factor (to gallons per $ft^2$). This converts the maximum applied water allowance from acre-inches per acre per year to gallons per square foot per year.

So, for a landscaped area of 50,000 $ft^2$. in Fresno:

$$MAWA = (ETo)(.8)(LA)(.62)$$

$$= (51\text{ inches})(.8)(50{,}000\text{ ft}^2)(.62)$$

$$= 1{,}264{,}800\text{ gallons per year (or 1,691 hundred-cubic-feet per year: } 1{,}264{,}800/748 = 1{,}691)$$

Portions of landscaped areas such as parks, playgrounds, sports fields, or schoolyards where turf provides a playing surface or serves other recreational purposes, are considered recreational areas and may require water in addition to the Maximum Applied Water Allowance. A statement should be included with the landscape design plan, designating recreational areas to be used for such purposes and specifying any needed amount of additional water above the Maximum Applied Water Allowance.

**Resources**

California Department of Water Resources Model Ordinance is described at: http://wwwdpla.water.ca.gov/cgi-bin/urban/conservation/landscape/ordinance/index.

Model reference evapotranspiration: http://wwwdpla.water.ca.gov/cgi-bin/urban/conservation/landscape/ordinance/section_495.

**Water Credit 1: Reduce Potable Water for Landscaping**

| | |
|---|---|
| 1 point | 1.1. Reduce potable water consumption for irrigation by 50% over landscape budget baselines with the use of water-efficient native (or adapted) climate-tolerant plantings, high-efficiency irrigation technologies, or using captured rain or municipally provided reclaimed water. |
| 2 points | 1.2. Reduce potable water for site irrigation by additional 50% (100% total reduction).<br>***OR*** do not install permanent landscape irrigation systems. |

Significant amounts of potable water are used to irrigate landscaping and playing fields even though non-potable water is equally effective. Water use is a growing issue in California, as expanding populations increase the demand for limited supplies of water. Patterns of precipitation in most of California make it difficult to store enough rainwater for irrigation through the long dry summers. High efficiency irrigation technologies such as micro irrigation, moisture sensors, or weather data-based controllers save water by reducing evaporation and operating only when needed. In urban areas, especially in Southern California, municipally supplied, reclaimed water is an available, less-expensive, and equally effective source for irrigation.

**References**

CHPS Best Practices Manual, Volume II: Guideline SP6: Drought Tolerant and Pest-Resistant Plants, Guideline SP10: Water-Efficient Irrigation Systems; Guideline SP12: Reclaimed Water for Irrigation.

LEED™ Reference Manual: Water Credit 1: Water Efficient Landscaping.

## Indoor Systems

Purpose: Maximize water efficiency within buildings to reduce the burden on municipal water supply and wastewater systems.

**Water Credit 2: Water Use Reduction**

| | |
|---|---|
| 1 point | 2.1. Reduce the use of municipally provided potable water for building sewage conveyance by a minimum of 50% through the utilization of water-efficient fixtures and/or using municipally supplied reclaimed water systems. |
| 1 point | 2.2. Employ strategies that, in aggregate, reduce potable water use by 20% beyond the baseline calculated for the building (not including irrigation) after meeting the Energy Policy Act of 1992's fixture performance requirements. |
| 2 points | 2.3. Exceed the potable water use reduction by 30% beyond the baseline. |

The growing value of potable water in California underlines the importance of lowering demand. Water efficiency naturally reduces the amount of water pumped from the ground or transported around the city or state. In addition, water efficiency reduces the cost and amount of sewage needing treatment after use. Because water-efficient devices can vary in quality and performance, specify only durable, high performance fixtures.

A maximum of three points can be earned with this credit. Well designed, water efficient systems may earn points by reducing the amount of potable water used for sewage conveyance (Credit 2.1), and up to two points by reducing the overall amount of potable water used in the schools (Credits 2.2 and 2.3).

Develop a water use baseline including all water consuming fixtures, equipment, and seasonal conditions according to methodology outlined below. Specify water conserving plumbing fixtures that exceed the Energy Policy Act of 1992's fixture requirements in combination with ultra high efficiency or dry fixture and control technologies. Specify high water efficiency equipment (dishwashers, laundry, cooling towers).

Credit 2.1. Use water-efficient fixtures and/or municipally supplied reclaimed water to reduce the amount of potable water used for sewage conveyance. Only those sources that produce blackwater, such as toilets and urinals, are included in this credit. Reclaimed water is suitable for flushing toilets and urinals, which typically produce the largest amounts of wastewater in a school.

To quantify water use reductions, create spreadsheets showing baseline and design water uses. List each fixture that produces blackwater, the amount of daily uses, number of occupants, and total water use. A water-efficient design for a 1,000-student school is shown below. The example assumes the use of low-flow toilets and waterless urinals, all using reclaimed water.

| Fixture Type | Flow-rate | Duration | Occupants | Daily Uses | Water Use (gal) |
|---|---|---|---|---|---|
| Low-flow Toilet (male) | 1.1 gal/flush | 1 flush | 500 | 1 | 550 |
| Waterless Urinal (male) | 0.0 gal/flush | 1 flush | 500 | 2 | 0 |
| Low flow Toilet (female) | 1.1 gal/flush | 1 flush | 500 | 3 | 1650 |
| | | | | **Total Daily Volume** | **2200** |
| | | | | **Number of School Days** | **180** |
| | | | | **Design Total Annual Volume** | **396,000** |
| | | | | **Minus Reclaimed Water Use** | **(396,000)** |
| | | | | **Total Potable Water Used for Sewage Conveyance** | **0** |

1. Calculate Daily Water Use per fixture using the following equation:

   Daily Water Use = (Flow-rate) (Duration)(Occupants)(Daily Uses)

2. Sum Daily Water Volumes for each fixture to find Total Daily Volume
3. Multiply the Total Daily Volume by the number of school days for Total Annual Volume.
4. Subtract the amount of reclaimed water used to find Total Potable Water Used for Sewage Conveyance

For the baseline calculation, create a similar spreadsheet but change only the type of fixture and its associated design details. For baseline calculations, assume flow rates outlined by the Energy Policy Act of 1992's fixture performance requirements:

| Fixture | EPA Requirements |
|---|---|
| Toilets | 1.6 gal/flush |
| Urinals | 1.0 gal/flush |
| Showerheads | 2.5 gal/min |
| Faucets | 2.5 gal/min |
| Replacement Aerators | 2.5 gal/min |
| Metering Faucets | 0.25 gal/cy |

The baseline calculation for this example would therefore be:

| Fixture Type | Flow-rate | Duration | Occupants | Daily uses | Water use (gal) |
|---|---|---|---|---|---|
| Conventional Toilet (male) | 1.6 gal/flush | 1 flush | 500 | 1 | 800 |
| Conventional Urinal (male) | 1.0 gal/flush | 1 flush | 500 | 2 | 1000 |
| Conventional Toilet (female) | 1.6 gal/flush | 1 flush | 500 | 3 | 2400 |
|  |  |  |  | **Total Daily Volume** | **4200** |
|  |  |  |  | **Number of School Days** | **180** |
|  |  |  |  | **Baseline Total Annual Volume** | **756,000** |

Comparing the two spreadsheets, the water-efficient fixtures reduced potable water use for sewage conveyance by:

% Savings = 1 – ( Design Total Annual Volume / Baseline Total Annual Volume)

= 1 – (0/756,0000) = 1.00 = 100%

Therefore, this design would earn one point because potable water used for sewage conveyance has been reduced by 100% through using reclaimed water in the toilets and urinals. Note that the low-flow fixtures by themselves were not enough to earn this credit.

Credits 2.2 and 2.3. These credits award reductions in total water use, therefore all water uses are included in the calculations. To quantify water use reductions, create spreadsheets showing baseline and design water uses. List each water-using appliance or fixture, the amount of daily uses, number of occupants, and total water use. Note that to determine the net amount of water used in the calculations, the amount of reclaimed water used for sewage conveyance is subtracted from the total amount of water used. A water-efficient design for the school shown in the previous example is shown below.

| Fixture Type | Flow-rate | Duration | Automatic Controls | Occupants | Daily uses | Water use |
|---|---|---|---|---|---|---|
| Low-flow Toilet (male) | 1.1 gal/flush | 1 flush | - | 500 | 1 | 550 |
| Waterless Urinal (male) | 0.0 gal/flush | 1 flush | - | 500 | 2 | 0 |
| Low-flow Toilet (female) | 1.1 gal/flush | 1 flush | - | 500 | 3 | 1650 |
| Bathroom Sink | 2.5 gal/min | .25 min | 20% saved | 1000 | 3 | 1500 |
| Low-flow Shower | 1.8 gal/min | 5 min | - | 100 | 1 | 900 |
| Low-flow Kitchen Sink | 1.8 gal/min | 45 min | - | 2 | 2 | 324 |
| Efficient Washing Machine | 20 gal/load | 1 load | - | - | 10 | 200 |

| | |
|---|---|
| **Total Daily Volume** | **5124** |
| **Number of -School Days** | **180** |
| **Subtotal** | **922,320** |
| **Minus amount of reclaimed water used** | **(396,000)** |
| **Design Total Annual Volume** | **526,320** |

For the baseline calculation, create a similar spreadsheet but change only the type of fixture and its associated design details. The baseline calculation for this example would therefore be:

| Fixture Type | Flow-rate | Duration | Automatic Controls | Occupants | Daily uses | Water use |
|---|---|---|---|---|---|---|
| Conventional Toilet (male) | 1.6 gal/flush | 1 flush | - | 500 | 1 | 800 |
| Conventional Urinal (male) | 1.0 gal/flush | 1 flush | - | 500 | 2 | 1000 |
| Conventional Toilet (female) | 1.6 gal/flush | 1 flush | - | 500 | 3 | 2400 |
| Bathroom Sink | 2.5 gal/min | .25 min | - | 1000 | 3 | 1875 |
| Conventional Shower | 2.5 gal/min | 5 min | - | 100 | 1 | 1250 |
| Kitchen Sink | 2.5 gal/min | 45 min | - | 2 | 2 | 450 |
| Clothes Washer | 40 gal/load | 1 load | - | - | 10 | 400 |

| | |
|---|---|
| **Total Daily Volume** | **8175** |
| **Number of School Days** | **180** |
| **Baseline Total Annual Volume** | **1,471,500** |

Comparing the two spreadsheets, the water-efficient fixtures reduced potable water use by:

% Savings = 1 – ( Design Total Annual Volume / Baseline Total Annual Volume)

= 1 – (526.320/1.471.500) = 0.64 = 64%

Therefore, this design would earn two points because overall potable water use has been reduced by over 30%.

**Resources**

CHPS Best Practices Manual, Volume II: OS6: Efficient Terminal Devices; OS7: Waterless Urinals.

LEED™ Reference Guide: Water Credit 2: Innovative Waste Water Technologies; Water Credit 3: Water Use Reduction.

# ENERGY

## Energy Efficiency

Purpose: Reduce environmental impacts and increased operational costs associated with excessive energy use.

**Energy Prerequisite 1: Minimum Energy Performance**

| | |
|---|---|
| *Required* | P1.1. The school design must exceed the Title 24-2001 California energy efficiency standards by 10%.<br>***OR*** the following prescriptive package energy conservation measures must be included in the design:<br>1. Energy efficient lighting with occupancy controls.<br>2. Economizers on packaged equipment. |

Energy-efficient schools save money while conserving non-renewable energy resources and reducing atmospheric emissions of pollutants and greenhouse gases. Since it's inception in the late 1970s, the state energy code, Title 24, has been very effective in reducing energy use: Californians are the second smallest energy user per capita in the nation. Title 24 was last updated in 2001, and although the code was made more stringent, there are numerous cost-effective, practical, and straightforward measures that can reduce energy use by over 30% from Title 24-2001. Note that Title 24-2001 currently covers only *regulated* energy, and does not include plug loads (including kitchen and lab equipment). School designs may comply with this credit by using performance or prescriptive approaches.

Energy efficiency will not happen in a vacuum. Commissioning, maintenance, and training are vitally important to the performance of the school and its systems. Commissioning involves a rigorous quality assurance program that ensures the building is designed appropriately and built as it is designed. No building can perform optimally without maintenance. Training is critically important to ensure that the teachers and maintenance staff understand how to maintain and operate the building systems. When turnover occurs, appropriate documentation must be on-hand to ensure that new team members are properly trained.

**Performance Approach.** The school must use 10% less source energy than the Title 24 baseline building. These calculations must be modeled in compliance with all the rules outlined in the California Alternative Compliance Manual (ACM). It provides guidance for establishing building base case development and analysis.

**Prescriptive Approach.** Alternatively, schools that incorporate the prescriptive package of energy conservation measures listed below are assumed to be at least 10% more efficient than Title 24-2001:

1. Use energy-efficient lighting and occupancy sensors to achieve an average adjusted lighting power density (LPD) of 0.95 W/ft$^2$ for the entire school. Energy-efficient lighting reduces the LPD directly by using less energy to deliver the same amount of light to the space. The CHPS Best Practices Manual dedicates an entire chapter to efficient lighting, including three classroom designs. The recommended approach is to install three rows of two-lamp suspended direct/indirect luminaries. Additional guidelines are provided for gyms, corridors, restrooms, libraries, and other spaces.

Occupancy sensors employ motion detectors to shut lights off in unoccupied spaces; they should be used in all classrooms, storage spaces, and offices where appropriate. Occupancy sensors are "control credits" in Title 24 that lower the adjusted LPD by 10-60% depending on the space type. Consult Title 24-2001 and the associated Non-Residential Manual and ACM Manual for more information.

To comply with this pre-requisite, use a weighted average of LPD by space type to calculate the average adjusted LPD for the entire school:

$$\text{Average Adjusted LPD} = \sum_{i=1}^{n} a_i LPD_i$$

Where:

n = number of spaces within the school with similar lighting and control designs.

a = the percent (expressed as a decimal) of the school square footage used by a particular space type, lighting design, and controls.

LPD = the lighting power density, adjusted appropriately for occupancy sensor "control credits" of a particular space type within the building.

2. Specify and install economizers on all package HVAC systems that utilize return air. Economizers save energy by using outside air instead of return air when it is more economical to do so. For example, if the outside air is closer to the desired thermostat setting than the return air, more outside air is used because less energy is needed to cool it. The moderate California climates allow economizers to be used frequently throughout the year, saving significant amounts of energy.

   *Integrated* economizers should be used whenever feasible. They are more energy efficient and require less maintenance than non-integrated economizers. Care must be taken to train the maintenance staff to ensure that the economizers are not disabled unnecessarily.

**Resources**

CHPS Best Practices Manual, Volume II. Energy efficiency is affected by most of the guidelines. In particular, consult the Daylighting, Electric Lighting, HVAC, Building Envelope, and Site Planning Chapters.

Three documents from the California Energy Commission give detailed descriptions of the state energy code. Access them all at http://www.energy.ca.gov.

- Title 24-2001 Regulations is the actual energy code text.
- The Nonresidential Manual thoroughly explains the nonresidential requirements of Title 24-2001. This is the reference for interpreting the code language.
- The Nonresidential Alternative Calculation Method (ACM) Approval Manual is primarily intended for those persons who want to design a calculation computer program for use with the energy standards. Because it describes all of the underling computer baseline and modeling assumptions, it is also used as a resource for those preparing energy models. The Nonresidential ACM Manual itself is not used for compliance with the Energy Efficiency Standards.

**Energy Credit 1: Superior Energy Performance**

1.1. By integrating the design of system components to increase energy efficiency, reduce the source energy of the proposed design to be below what is required by the California energy efficiency standards (Title 24).

| | |
|---|---|
| 2 points | 15% reduction in total net energy use compared to Title 24-2001 baseline. |
| 4 points | 20% reduction in total net energy use compared to Title 24-2001 baseline. |
| 6 points | 25% reduction in total net energy use compared to Title 24-2001 baseline. |
| 8 points | 30% reduction in total net energy use compared to Title 24-2001 baseline. |
| 10 points | 35% reduction in total net energy use compared to Title 24-2001 baseline. |

*OR*

| | |
|---|---|
| 4 points | Incorporating the following design elements into the school:<br>1. All of the prescriptive measures detailed in Energy Prerequisite 1.<br>2. Daylighting, with daylighting controls installed on 40% of lights.<br>3. Radiant barrier or increased roof insulation. |

Investments in energy efficiency measures are cost-effective, and net reductions of 20% to 30% are feasible. A wide array of measures can reduce energy use, with the amount of energy saved depending on local climate, the quality of the design, whether the interactions between the building systems have been optimized, the extent of commissioning, and the amount of training given to teachers and staff. Consider opportunities throughout the school in the following areas:

- Daylighting: optimize the daylighting design to minimize glare and eliminate direct beam light in the classroom, use daylighting controls designed to dim or turn-off electric lights when sufficient daylight is available.
- HVAC systems: use high efficiency equipment, correctly size for the estimated demands of the facility, use economizers and other controls that optimize system performance.
- Electric lighting: use high efficiency products, optimize the number of light fixtures in each room, use occupant sensors and other control devices that ensure peak system performance, successfully integrate electric lighting and daylighting strategies.
- Enclosure: Ensure that walls, floors, roofs, and windows of the school are as energy efficient as cost-effectively possible.
- Commissioning. Commissioning is increasingly important as more savings are expected through energy conservation measures. It ensures that the school is built as designed, and operates as expected. See Credit 4: Commissioning for more information.

**Performance Approach.** Include additional integrated design measures to increase the energy efficiency of the school. Perform energy analysis for selected design elements that affect energy performance and document compliance. Follow the requirements and guidelines outlined in the Title 24 ACM manual. The unit of measure for performance is source energy. The design earns from two to 10 points, based on the level of savings achieved. Interpolation to whole number point levels is allowed. For example, 22.5% savings would earn five points. Extrapolation is not allowed.

**Prescriptive Approach.** Alternatively, designs that incorporate the following measures are assumed to save 20% of baseline energy and therefore earn four points:

1. All measures detailed in the prescriptive approach of Energy Prerequisite 1.

2. Use daylighting and dimming controls. Incorporate daylighting throughout the school so that 40% of the installed electrical lighting is dimmed or turned off when sufficient natural light is present. Lighting controls can be "dimming" or "stepping" technologies. All school spaces can be designed to utilize natural daylight, but classrooms should be prioritized due to the proven correlations between quality daylighting design and improved student performance. Daylighting is encouraged throughout all spaces in the school.
3. Use a radiant barrier in the attic following the guideline in the CHPS Best Practices Manual (Guideline IN4: Radiant Barriers). Radiant barriers lower cooling loads by reflecting solar radiation before it can penetrate and heat building interiors.

**Resources**

CHPS Best Practices Manual, Volume II. Much of Volume II is dedicated to energy efficient design strategies including the chapters on Daylighting, Electric Lighting, HVAC, and Building Envelope.

LEED™ Reference Guide: Energy and Atmosphere Credit 1: Optimize Energy Performance.

### Energy Credit 2: Natural Ventilation

| | |
|---|---|
| 1 point | 2.1. Install interlocks to turn off HVAC systems if operable windows or doors are opened. |
| 3 points | 2.2. Design 90% of permanent classrooms without air conditioning. |

Credit 2.1. It is recommended that each classroom have an operable window. IEQ Credit 1 (Daylighting) has one point for view windows in classrooms and IEQ Credit 6 (Teacher Control) offers another credit if the window is operable. However, care must be taken to properly control the operable windows with interlocked controls.

Each year, significant amounts of energy are lost when teachers or staff members open exterior doors or windows while HVAC systems are operating. Interlocks should be installed to stop HVAC systems when windows and doors are opened for extended periods. Controls must be included so that normal use of the doors does not cause the HVAC systems to cycle on and off unnecessarily, and teachers must be educated on how the system works and why it is needed. In addition, the interlocks should not turn off the ventilation fans, only the mechanical compressors. Adequate amounts of ventilation must be supplied to the classroom at all times.

However, with proper design and adequate maintenance, teachers should have no *reason* to open the doors. If the ventilation system cannot remove stale air and odors, teachers are often forced to open exterior doors or windows to improve comfort. Portables are particularly susceptible to this problem, especially if the HVAC systems are not ducted. Other times, in spaces with small or no windows, teachers and staff open the doors for a connection to the outdoors. Both of these issues can, and should, be addressed with better design and adequate maintenance. Insufficient ventilation can have serious health effects on the students, teachers, and other staff members.

Credit 2.2. Natural ventilation is a comfortable, effective, and efficient option for some climate zones in California. It is critically important to verify that required ventilation levels can be maintained through natural ventilation, and that no outdoor pollutants (from traffic, industrial sources, or the potential for air quality emergencies) eliminate its feasibility. To meet Title 24 ventilation standards, all occupants must be within 20 feet of an operable window. For a standard classroom, this would require that operable windows be installed on both sides. If this design is not possible, ventilation systems with exhaust fans would need to be installed to provide the minimum required ventilation levels. In-line fans designed for radon removal provide one low-power option.

Air conditioning systems prohibited by this credit include all air- and water-source packaged air conditioners or heat pumps. Direct/indirect evaporative systems without compressed refrigerant can be used and still receive this credit.

**Resources**

CHPS Best Practices Manual, Volume II: Guideline TC1: Cross Ventilation; Guideline TC2: Stack Ventilation; Guideline TC3: Ceiling Fans.

# Alternative Energy Sources

Purpose: Reduce environmental impacts and increased operational costs associated with excessive energy use.

**Energy Credit 3: Renewable Energy and Distributed Generation**

3.1. Use on-site renewable energy and distributed generation for a portion of a school's energy use. The table below shows the point levels corresponding to the percentage of net energy use supplied by alternative sources.

| For Renewable Energy Sources | For On-site Distributed Generation | % of Net Energy Supplied from Alternative Sources |
|---|---|---|
| 2 points | 1 point | 5% |
| 3 points | 1 point | 7.5% |
| 4 points | 2 points | 10% |
| 5 points | 3 points | 20% |
| 6 points | 4 points | 50% |

Employ on-site renewable energy technologies or distributed generation to supply part of the building energy. Systems include:

| Renewable Energy Sources | Distributed Generation |
|---|---|
| Photovoltaics | Fuels cells utilizing non-renewable fuels and waste heat recovery. |
| Wind | |
| Geothermal (not including ground source heat pumps) | Microturbine utilizing waste heat recovery. |
| Fuel cells utilizing biogas | |

On-site renewable energy and distributed generation have many benefits. Renewable sources, such as photovoltaics, wind turbines, and geothermal sources, use the sun, air, and earth instead of non-renewable, polluting sources, such as coal or natural gas. The distributed generation systems listed in the table above all use non-renewable fuels. However, their improved efficiencies and technologies produce less air pollutants than traditional, centrally-located coal or natural gas plants. Fuel cells can be powered by either renewable (biogas) or non-renewable (natural gas) sources, and are included in both categories.

Sources covered under this credit must be located at the school site, eliminating the environmental impacts and transmission losses associated with remote sources. On-site sources can become very effective components of school curriculums, educating students on a wide variety of energy and science issues. Off-site renewables are covered under District Credit 5 Green Power.

The costs and feasibility of on-site renewables and distributed generation vary significantly with location, technology, site-specific constraints, and maintenance concerns. Typical school installations supply less than 5% of total energy. Renewable systems generally reach a point of diminishing returns before they supply 100% of total energy. Incentive or "buy-down" programs from state or local energy providers can substantially reduce first-costs.

Sources should be installed using net metering. Net metering attaches the on-site system to the electrical power grid. When the school produces more energy than it is uses, the excess energy is traded back to the local energy provider. In essence, this "spins the meter backwards" and is vital to the cost-effectiveness of the system. At the time of this writing (Fall 2001), facilities with on-site renewables and net metering could only receive credit up to the amount of energy they used. In other words, buildings could only "zero-out" their utility bill and not make a profit from selling their excess energy.

To earn points with this credit:

1. Model the school building to estimate the amount of energy used annually ($Q_{school}$). Employ figures from Energy Prerequisite 1 or Energy Credit 1 if the performance approach is used.
2. Calculate the amount of energy the particular on-site renewable or distributed generation system can supply annually ($Q_{alternative}$).
3. Calculate the net amount of energy provided by renewables ($Q_{alternative}/Q_{school}$).

**Resources**

CHPS Best Practices Manual, Volume II: Guideline OS1: Photovoltaics.

LEED™ Reference Guide: Energy and Atmosphere Credit 2: Renewable Energy.

# Commissioning and Training

Purpose: Verify that fundamental building elements and systems are designed, installed, and calibrated to operate as intended, and provide for the ongoing accountability and optimization of building energy performance over time.

**Energy Prerequisite 2: Fundamental Building Systems Testing and Training**

| | |
|---|---|
| *Required* | P2.1. A third party or district official must verify that the following critical building systems have been tested prior to occupancy:<br>▪ Controls (daylight, occupancy, light switching).<br>▪ HVAC (ducts, economizers, timeclocks, air balance, airflow, refrigerant charge).<br>▪ Energy Management System. |
| *Required* | P2.2. Effective and complete training and documentation must be provided, including a complete guide for staff, short operations briefs for all classrooms, and facilitation of training programs for school administrators, teachers, and staff. Training is an essential step to protect indoor air quality and maintain superior energy performance. Maintenance and record keeping must meet the requirements of the Cal/OSHA Minimum Building Ventilation Standard, Title 8, Sec. 5142. |

Prerequisite P2.1. Verification of system performance and training of staff is typically included in current practice. However, this prerequisite requires a third party or district official to perform, monitor, or verify the testing. Training the teachers and staff is essential to performance of the building, but often it is either not performed or hastily completed.

Prerequisite P2.2. The design and construction of the school may incorporate all the latest high performance features, yet problems can occur simply because important information was not transferred from the design and construction teams to the teachers and other school staff. The following required actions help ensure that the facilities staff, teachers, and others understand their role.

- Operations &Maintenance Manual: Provides detailed operations and maintenance information for all equipment and products in use in the school. A short, classroom "user's guide" must be created for teachers explaining how to operate their room lighting and HVAC systems.
- O&M Training: Provides a short introduction for all school staff, and then features a special hands-on workshop for facility personnel.
- Cal/OSHA requirements are available online at: http://www.dir.ca.gov/title8/5142.html. The regulations include:
  1. The HVAC system shall be inspected at least annually, and problems found during these inspections shall be corrected within a reasonable time.
  2. Inspections and maintenance of the HVAC system shall be documented in writing. The employer shall record the name of the individual(s) inspecting and/or maintaining the system, the date of the inspection and/or maintenance, and the specific findings and actions taken. The employer shall ensure that such records are retained for at least five years.

3. The employer shall make all records required by this section available for examination and copying, within 48 hours of a request, to any authorized representative of the Division (as defined in Section 3207), to any employee of the employer affected by this section, and to any designated representative of said employee of the employer affected by this section.

**Resources**

CHPS Best Practices Manual, Volume II: Guideline GC5: Contractor's Commissioning Responsibilities.

### Energy Credit 4: Commissioning

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| 2 points | 4.1. Implement ***ALL*** of the following fundamental best practice commissioning procedures:<br>1. Engage a commissioning agent.<br>2. Develop design intent and basis of design documentation.<br>3. Include commissioning requirements in the construction documents.<br>4. Develop and utilize a commissioning plan.<br>5. Verify installation, functional performance, training, and documentation.<br>6. Complete a commissioning report. |
| 1 point | 4.2. In addition to Credit 4.1 above, implement the following commissioning tasks:<br>1. Conduct a focused review of the design prior to the construction documents phase.<br>2. Conduct a focused review of the construction documents when close to completion.<br>3. Conduct a selective review of contractor submittals of commissioned equipment.<br>4. Develop a system and energy management manual.<br>5. Have a contract in place for a near-warranty end, or post-occupancy, review.<br>Note: The design firm cannot perform items 1, 2, and 3. |

Do not underestimate the value of commissioning.

Buildings, even simple structures, are complex systems of electrical, mechanical, and structural components. High performance buildings are healthy, efficient, environmentally sensitive structures whose performance can be significantly affected if the building has not been designed following the district's intent or constructed according to the designers' specifications. Commissioning is a rigorous quality assurance program administered by a knowledgeable third party that ensures the building performs as expected.

The requirements of this credit are split into two levels of commissioning. The first credit (4.1) should be a part of all school construction programs. The second credit (4.2) expands the scope to include design, construction documentation, and submittal review.

Credit 4.1. Worth two points, this credit requires the following commissioning procedures. For a more thorough discussion of the requirements, see the LEED™ Reference Guide: -Energy Prerequisite 1.

1. **Engage a commissioning agent.** The commissioning agent (CA) directs the commissioning process and should be engaged as early in the design as possible. CHPS recommends that the CA be an independent third party. If this is not possible, a member of the design firm may be designated for this role as long as he or she is not responsible for project design, construction management, or supervision.

2. **Develop design intent and basis of design documentation.** The CA must write a list of the owner's requirements and design intent for each of the systems or features to be commissioned.
3. **Develop commissioning plan.** The commissioning plan includes a list of all equipment to be commissioned, delineation of roles for each of the primary commissioning participants, and details on the scope, timeline, and deliverables throughout the commissioning process.
4. **Include commissioning requirements in the construction documents.** All commissioning requirements must be integrated into the construction documents to clearly specify the responsibilities and tasks to be performed. Of particular importance are the delineation of the contractors' responsibilities and the creation of the Operations and Maintenance Manuals.
5. **Verify installation, functional performance, training, and documentation for each commissioned system and feature.**
6. **Complete a commissioning report.** The report must show that the building's systems have met the design intent and specifications, have been properly installed, are performing as expected, and that proper O&M documentation and training have been provided.

Credit 4.2. This credit expands the role of the CA to include review of the design, construction documents, and submittals beyond the tasks required by Credit 4.1. In addition, the CA must develop an indexed Recommissioning Management Manual and return for a post-occupancy review of the school. For a more thorough discussion of the requirements, see the LEED™ Reference Guide: Energy and Atmosphere Credit 3.

**Resources**

CHPS Best Practices Manual, Volume II: Guideline GC5: Contractor Commissioning Responsibilities.

LEED™ Reference Manual: Energy and Atmosphere Prerequisite 1: Energy and Atmosphere Credit 3.

### Energy Credit 5: Energy Management Systems

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| 1 point | 5.1. Install an Energy Management System to monitor the energy use of the following systems throughout the school (including all portables):<br>▪ Lighting (Internal and external)<br>▪ Equipment (plug loads)<br>▪ HVAC (heating, cooling, fans)<br>▪ Hot water;<br>***AND*** either the Energy Management System or other devices (e.g. occupancy sensors) must control all lighting and HVAC systems to Title 24 minimum standards in all spaces, including portables used on the school site. |

Energy management systems (EMS) are typically installed in new schools. However, care must be taken to specify and install an appropriate system for the district and maintenance staff. An appropriate EMS is the simplest system that still addresses the school's needs. Increased complexity does not always mean increased value for the district. EMS systems can potentially save significant energy, but only if the staff understands how to operate it. Proper training of district staff is critical, and high turnover rates continue to challenge school districts.

Monitoring capabilities should allow for comparison between various types of building loads throughout all spaces of the school (including portables). This information is valuable and can be used to manage and optimize energy use. Minimum control capabilities are necessary to implement Title 24 requirements.

**Resources**

CHPS Best Practices Manual, Volume II: Guideline TC23: Adjustable Thermostats; Guideline TC24: EMS/DDC; Guideline EL4: Lighting Controls for Classrooms.

# MATERIALS

## Waste Reduction and Efficient Material Use

Purpose: Reduce the amount of construction and occupant waste entering the landfill and promote the efficient reuse of materials and buildings.

### Materials Prerequisite 1: Storage and Collection of Recyclables

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|---|---|
| *Required* | P1.1. The building/school shall meet local ordinance requirements for recycling space;<br>***AND*** provide an easily accessible area serving the entire school that is dedicated to the separation, collection, and storage of materials for recycling including—at a minimum—paper (white ledger, mixed, and cardboard), glass, plastics, and metals. |

In California, many local governments have developed ordinances relating to adequate areas for collection and loading of recyclable materials in development projects. Areas without local ordinances should use the model ordinance developed by the California Integrated Waste Management Board and detailed in Appendix A of the Recycling Space Allocation Guide. (http://www.ciwmb.ca.gov/publications/localasst/31000012.doc).

Reserve space for recycling functions early in the building occupancy programming process and show areas dedicated to the collection of recycled materials on space utilization plans. Broader recycling space considerations should allow for collection and storage of the required elements, as well as the recycling of newspaper, organic waste (food and soiled paper), and dry waste. When collection bins are used, they should be able to accommodate a 75% diversion rate and be easily accessible to custodial staff and recycling collection workers. Consider bin designs that allow for easy cleaning to avoid health issues. Ensure that the spaces are synergistic with the policies of local waste handling companies.

**Resources**

California Integrated Waste Management Board Recycling Space Allocation Guide (http://www.ciwmb.ca.gov/publications/localasst/31000012.doc).

## Materials Credit 1: Site Waste Management

Meet local ordinance requirements concerning construction and demolition materials at construction sites, if applicable;

*AND* develop and implement a waste management plan, quantifying material diversion by weight to:

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|---|---|
| 1 point | 1.1. Recycle, compost, and/or salvage at least 50% (by weight) of construction, demolition, and land clearing waste. |
| 2 points | 1.2. Recycle, compost, and/or salvage at least 75% (by weight) of the construction, demolition, and land clearing debris. |

Develop and specify a waste management plan that identifies licensed haulers and processors of recyclables; identifies markets for salvaged materials; employs deconstruction, salvage, and recycling strategies and processes; includes waste auditing; and documents the cost for recycling, salvaging, and reusing materials. Source reduction on the job site should be an integral part of the plan.

The plan should address recycling of corrugated cardboard, metals, concrete brick, asphalt, land clearing debris (if applicable), beverage containers, clean dimensional wood, plastic, glass, gypsum board, and carpet. It must also evaluate the cost-effectiveness of recycling rigid insulation, engineered wood products, and other materials.

Compliance calculations for this credit must be based on weight. Many recycling and landfill facilities weigh incoming materials. Shipments that cannot be weighed can be estimated based on their volume and density.

$$\text{Recycle Rate (\%)} = \frac{\text{Recycled Waste [Tons]}}{\text{Recycled Waste [Tons]} + \text{Garbage [Tons]}} \times 100$$

### Resources

CHPS Best Practices Manual, Volume II: Guideline GC2: Construction and Demolition Waste Management.

LEED™ Reference Guide: Materials Credit 2: Construction Waste Management.

**Materials Credit 2: Building Reuse**

Earn one of the following credits.

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| 1 point | 2.1. Reuse large portions of existing structures during renovation or redevelopment projects. Maintain at least 75% of existing building structure and shell (exterior skin and framing, excluding window assemblies). |
| 2 points | 2.2. Maintain an additional 25% (100% total) of existing building structure and shell (exterior skin and framing, excluding window assemblies). |
| 3 points | 2.3. Maintain 100% of existing building structure and shell; ***AND*** 50% non-shell (walls, floor coverings, and ceiling systems). |

Reusing parts of the building can save significant money and resources, while greatly reducing the amount of construction waste. When materials are re-used, the environmental benefits start with resource savings and extend down through the entire lifecycle of the material: less energy is spent extracting, processing, and shipping the materials to the site. Depending on the amount of building re-used, school districts can significantly reduce their construction and material costs. However, the building envelope will significantly affect many important high performance areas, such as space programming, energy performance, opportunities for daylighting, and indoor air quality. In addition, care must be taken to ensure that any environmental hazards such as toxins, lead, and asbestos have been identified and addressed. Develop a list of benefits and tradeoffs, and make the decision based upon the overall, integrated design tradeoffs.

Credits 2.1 and 2.2. Percentage of reused structures materials (foundation, slab on grade, beams, floor and roof decks, etc) should be approximated in terms of cubic feet, while shell materials (roof and exterior walls) should be estimated in square feet. Average together the structural and shell reuse percentages for an approximated building reuse factor.

$$\text{Building Reuse (\%)} = \frac{\dfrac{\text{Reused Structural Elements[cf]}}{\text{Total Structual Elements[cf]}} + \dfrac{\text{Reused Shell Elements}[\text{ft}^2]}{\text{Total Shell Elements}[\text{ft}^2]}}{2}$$

Credit 2.3. Percentage of reused, non-shell building portions will be calculated as the total area ($\text{ft}^2$) of reused walls, floor covering, and ceiling systems, divided by the existing total area ($\text{ft}^2$) of walls, floor covering, and ceiling systems.

**Resources**

LEED™ Reference Guide: Materials Credit 1: Building Reuse.

### Materials Credit 3: Resource Reuse

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|---|---|
| 1 point | 3.1. Specify salvaged or refurbished materials for 5% of building materials. |
| 2 points | 3.2. Specify salvaged or refurbished materials for 10% of building materials. |

Re-used materials or products are salvaged from a previous use or application and then used in a new use or application with only superficial modification, finishing, or repair. Commonly salvaged building materials include wood flooring/paneling/cabinets, doors and frames, mantels, ironwork and decorative lighting fixtures, brick, masonry, heavy timbers, and on-site concrete used as aggregate. Ensure the salvaged materials, especially structural elements, comply with all applicable codes.

Base percentage calculations in terms of dollar value:

$$\text{Salvage Rate [\%]} = \frac{\text{Salvaged Material Cost[\$]}}{\text{Total Material Cost[\$]}} \times 100$$

Exclude all labor costs, all mechanical and electrical material costs, and project overhead and fees. If the cost of the salvaged or refurbished material is below market value, use replacement cost to estimate the material value; otherwise use actual cost to the project. Total material cost is used as the basis of the sustainable material credits.

**Resources**

CHPS Best Practices Manual, Volume II: Material Selection and Research Section; Interior Surfaces and Furnishings Chapter.

LEED™ Reference Guide: Materials Credit 3: Resource Reuse.

## Sustainable Materials

Purpose: Increase demand for building products that have incorporated recycled-content material, reducing the impacts resulting from extraction of new material; reduce the use and depletion of finite raw and long-cycle renewable materials by replacing them with rapidly renewable materials; encourage environmentally-responsible forest management.

**Materials Credit 4: Recycled Content**

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| 1 point | 4.1. Performance Approach: Achieve a minimum recycled content rate of 25% following either:<br>▪ Option1: A weighted average postconsumer recycled-content calculation that rewards products that exceed 20% postconsumer recycled-content material.<br>▪ Option 2: A summation of all recycled-content materials that each contain a minimum of 50% total recycled content with at least 10% postconsumer recycled content.<br>OR Prescriptive Approach: Specify at least four major materials from the Construction Products category of the EPA Comprehensive Procurement Guidelines 2000 Buy-Recycled Series. |
| 2 points | 4.1. Performance Approach: Achieve a minimum recycled content rate of 50% following either:<br>▪ Option1: A weighted average postconsumer recycled-content calculation that rewards products that exceed 20% postconsumer recycled-content material,<br>▪ Option 2: A summation of all recycled-content materials that each contain a minimum of 50% total recycled content with at least 10% postconsumer recycled content<br>OR Prescriptive Approach: Specify at least eight major materials from the EPA Comprehensive Procurement Guidelines. At least six building materials must be from the Construction Products Category. |

The number and variety of products using recycled-content materials expands every year. Using these materials closes the recycling loop by creating markets for materials collected through recycling programs across the country. It also reduces the use of virgin materials and landfill waste. Recycled-content alternatives exist for all major building materials and surfaces. Recycled content is either a postconsumer (collected from end users) or secondary material. Secondary material (also known as post-industrial or pre-consumer) is collected from manufacturers and industry. The objective is to maximize postconsumer recycled content.

The US EPA's Comprehensive Procurement Guideline (CPG) program provides fact sheets for various product categories as well as a list of materials with recommended recycled-content levels. The California Integrated Waste Management Board (CIWMB) Recycled-content Products Database allows you to search for a recycled-content product by product/brand name, company, or keyword. Each product in the database has information on the total recycled content as well as the postconsumer recycled content.

**Performance Approach.** Chose either option below to earn points in this credit.

Option 1: This option only considers postconsumer recycled content. The weighted average calculation methodology outlined below rewards materials that contain at least 20% postconsumer material by weighting them more heavily. Products with less than 20% are penalized.

1. Sum the Material Cost for all products used in the school to find the **Total Project Material Cost**. Material cost is the construction cost of a material excluding all labor and equipment (mechanical and electrical materials) costs, project overhead, and fees.
2. For each material, calculate the **Postconsumer Recycled-content Value**.

$$\text{Postconsumer Recycled-content Value [\$]} = \text{Material Cost} \times \frac{\text{Post - consumer Recycled - content [\%]}}{20\%}$$

3. Sum these values to obtain the **Total Postconsumer Recycled Content Value.**
4. Calculate the **Recycled-content Rate (%).**

$$\text{Recycled-content Rate [\%]} = \frac{\text{Total Postconsumer Recycled - content Value [\$]}}{\text{Total Project Material Cost [\$]}}$$

Earn 1 point if: Recycled-content Rate (%) = 25%.

Earn 2 point if: Recycled-content Rate (%) = 50%.

Option 2: This option is consistent with California's State Agency Buy Recycled Campaign (SABRC). Only products with at least 50% total recycled content with a minimum of 10% postconsumer recycled content are included in the calculation.

1. Create a table of all materials used in the project including information on total recycled content and postconsumer recycled content. Sum the cost of all materials used to come up with the **Total Project Material Cost.**
2. Sum the cost of all materials that each have at least 50% total recycled content with a minimum of 10% postconsumer recycled content to find the **Total Recycled-content Material Cost**.
3. Divide the **Total Recycled-content Material Cost** by the **Total Project Material Cost** and multiply by 100 to come up with the total recycled-content rate.

$$\text{Recycled-content Rate [\%]} = \frac{\text{Total Recycled - content Material Cost [\$]}}{\text{Total Project Material Cost [\$]}}$$

Earn 1 point if: Recycled-content Rate (%) = 25%.

Earn 2 point if: Recycled-content Rate (%) = 50%.

**Prescriptive Approach.** Credit 4.1. Specify at least four major materials from the Construction Products category of the EPA Comprehensive Procurement Guidelines 2000 Buy-Recycled Series. A "major" material is defined as those materials covering more than 50% of a major building surface (such as parking areas, floor, roof, partitions, walls), or serving a structural function throughout the majority of the building. EPA's Comprehensive Procurement Guidelines are available at: http://www.epa.gov/cpg. For the purposes of these prescriptive points, nylon carpeting with at least 50% recycled-content materials can be used in addition to the carpet with recycled polyester (PET resin) materials listed on the EPA's site. Some PET carpets do not have enough durability for commercial applications.

Credit 4.2. Eight major materials must be specified from the EPA's Comprehensive Procurement Guidelines, and at least six must be from the construction products category.

**Resources**

CHPS Best Practices Manual, Volume II: Interior Surfaces and Finishes Chapter.

LEED™ Reference Guide: Materials Credit 4: Recycled Content.

State Agency Buy Recycled Campaign (SABRC) at http://www.ciwmb.ca.gov/BuyRecycled/StateAgency/

California Integrated Waste Management Board (CIWMB) Recycled-content Products Database: http://www.ciwmb.ca.gov/rcp

EPA's Comprehensive Procurement Guideline (CPG) Program: http://www.epa.gov/cpg

### Materials Credit 5: Rapidly Renewable Materials

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|---|---|
| 1 point | 5.1. Specify rapidly renewable building materials for 5% of total building materials. |

Rapidly renewable resources are those materials that substantially replenish themselves faster than traditional extraction demand (e.g. planted and harvested in less than a 10 year cycle); do not result in significant biodiversity loss, increased erosion, and air quality impacts; and that are sustainably managed. Products in this category include, but are not limited to, bamboo products, wheat grass cabinetry, oriented strand board and other wood products made from fast-growing poplar and Monterey pine trees, and linoleum. Ensure that the products protect indoor air quality and are durable.

To earn this credit, determine the percentage of total building materials from rapidly renewable sources. Exclude all labor costs, all mechanical and electrical material costs, and project overhead and fees.

$$\text{Rapidly Renewable Material Portion [\%]} = \frac{\text{Rapidly Renewable material cost[\$]}}{\text{Total material cost[\$]}} \times 100$$

**Resources**

CHPS Best Practices Manual: Volume II: Interior Surfaces and Finishes Chapter.

LEED™ Reference Guide: Materials Credit 6: Rapidly Renewable Materials.

### Materials Credit 6: Certified Wood

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|---|---|
| 1 point | 6.1. Use a minimum of 50% of wood-based materials certified in accordance with the Forest Stewardship Council guidelines for wood building components. This includes, but is not limited to, framing, flooring, finishes, furnishings, and non-rented temporary construction applications such as bracing, concrete form work, and pedestrian barriers. |

Refer to the Forest Stewardship Council guidelines for wood building components that qualify for compliance to the requirements and incorporate them into the material selection for the project.

For earn this credit, determine the percentage of total new wood based products that are FSC-certified. Exclude all labor costs, all mechanical and electrical material costs, and project overhead and fees.

$$\text{Certified Wood Material Portion [\%]} = \frac{\text{FSC Certified Wood Products Cost cost [\$]}}{\text{Total New Wood Based Products cost[\$]}} \times 100$$

**Resources**

CHPS Best Practices Manual, Volume II: Guideline IS5: Wood Flooring; Guideline IS11: Casework and Trim; Guideline IS12: Interior Doors.

LEED™ Reference Guide: Materials Credit 7: Certified Wood.

# INDOOR ENVIRONMENTAL QUALITY

## Daylighting

Purpose: Improve student productivity through quality daylighting designs that minimize glare and direct sunlight penetration. Provide a connection between indoor spaces and the outdoor environment through the introduction of sunlight and views into the occupied areas of the building.

**IEQ Credit 1: Daylighting in Classrooms**

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|---|---|
| 3 points | 1.1. Achieve a 2% minimum Daylight Factor of uniformly distributed daylighting with no direct sunlight penetration in 75% of all classroom space, not including copy rooms, storage areas, mechanical, laundry, and other low occupancy support areas. |
| 1 point | 1.2. Direct line of sight to vision glazing from 90% of classrooms, administration areas, and all regularly occupied spaces, not including copy rooms, storage areas, mechanical, laundry, and other low occupancy support areas. |

Credit 1.1. Daylighting is fundamentally important to high performance design, and should be the primary source of light in classrooms.

To earn this credit, 75% of the classrooms in the school must have a minimum Daylight Factor of 2%. The Daylight Factor is simply the ratio of exterior to interior illumination:

$$\text{Daylight Factor [\%]} = \frac{\text{Light at Task Levels in Classroom [fc or lux]}}{\text{Outdoor Daylight [fc or lux]}} \times 100$$

Follow the guidelines in the Daylighting Chapter of the CHPS Best Practices Manual to create a suitable daylighting strategy. Daylighting in classrooms must be uniformly distributed, with no direct-beam, sunlight penetration and minimized glare. The guidelines thoroughly discuss several different approaches to classroom daylighting, including the use of clerestories, light shelves, and toplighting.

Always orient the school to maximize daylighting options. Do not overglaze the space. Daylighting in classrooms should not exceed 200 footcandles during peak periods.

Credit 1.2. To earn this credit, 90% of all classroom, administration areas, and other regularly occupied spaces must contain direct line of sight glazing to the outdoors. Windows below 2.5' or above 7.5' do not qualify.

**Resources**

CHPS Best Practices Manual: Volume II: Daylighting and Fenestration Design Chapter.

LEED™ Reference Guide: Indoor Environmental Quality Credit 8: Daylighting.

## Indoor Air Quality

Purpose: Achieve good indoor air quality to protect student and staff health, performance, and attendance.

**IEQ Prerequisite 1: Minimum Requirements**

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| *Required* | P1.1. Meet the performance requirements of Cal/OSHA Minimum Ventilation Standard, Title 8, Sec. 5142,including:<br>(a) Design building ventilation systems to ensure that the continuous delivery of outside air is no less than the governing design standard (currently CEC Title 24: 15 cfm per person);<br>(b) ***AND*** will occur at all times rooms are occupied. The design must ensure that the supply operates in continuous mode and is not readily defeated (i.e., blocked registers or windows) during occupancy periods. |
| *Required* | P1.2. Meet the minimum requirements of voluntary consensus standard ASHRAE 62-1999, Ventilation for Acceptable Indoor Air Quality for areas not covered by Cal/OSHA Minimum Ventilation Standard. |
| *Required* | P1.3. All surface grades, drainage systems, and HVAC condensate must be designed to prevent the accumulation of water under, in, or near buildings (especially portables). |
| *Required* | P1.4. Irrigation systems must not spray on buildings. |
| *Required* | P1.5. During construction, meet or exceed all of the following minimum requirements:<br>▪ Mold protection: Building materials, especially those like wood, porous insulation, paper, and fabric, should be kept dry to prevent the growth of mold and bacteria. Cover these materials with plastic to prevent rain damage, and if resting on the ground, use spacers to allow air to circulate between the ground and the materials. Water damaged materials should be dried within 24 hours. Due to the possibility of mold and bacteria growth, materials that are damp or wet for more than 72 hours may need to be discarded. Immediately remove materials showing signs of mold and mildew, including any with moisture stains, from the site and properly dispose of them. Replace moldy materials with new, undamaged materials.<br>▪ Filters: Replace all filtration media immediately prior to occupancy. Filtration media shall have a Minimum Efficiency Reporting Value (MERV) of 13 as determined by ASHRAE 52.2-1999. |

Supplying non-polluted outdoor air ventilation to classroom areas is critical to the protection of good indoor air quality. Ensure that the ventilation system's outdoor air capacity can meet standards in all modes of operation. Locate building outdoor air intakes away from loading areas, building exhaust fans, cooling towers, and other sources of contamination.

Note that compliance with code minimums will not ensure good indoor air quality. Minimizing emissions from materials (IEQ Credit 2), controlling point sources of pollution (Credit 3), performing measures during construction (IEQ Credit 4), commissioning (Energy Credit 4), and regular maintenance (District Credit 3) are all critically important to protecting indoor air quality.

For intake sitings, consider both current and future traffic and development patterns and consult the local Air Pollution Control Officer to locate nearby emission sources. Local air quality may impact decisions to use natural ventilation or may justify improved air filtration.

P1.1. All regularly occupied spaces must be ventilated. Cal/OSHA requires that the HVAC shall be operated continuously during working hours except:

- during scheduled maintenance and emergency repairs.
- during periods not exceeding a total of 90 hours per calendar year when a serving electric utility by contractual arrangement requests its customers to decrease electrical power demand.
- during periods for which the employer can demonstrate that the quantity of outdoor air supplied by non-mechanical means meets the outdoor air supply rate required by Title 24.

The Cal/OSHA requirements are available at: http://www.dir.ca.gov/title8/5142.html.

P1.2. For areas not covered by Cal/OSHA, ventilation systems must meet the minimum requirements of voluntary consensus standard ASHRAE 62-1999, Ventilation for Acceptable Indoor Air Quality.

P1.3. Due to extreme health risks that can be caused by mold and microbial growth, all surface grades, drainage systems, and HVAC condensate must be designed to prevent the accumulation of water under, in, or near buildings. Portables are particularly vulnerable, and must be placed on properly drained surfaces.

P1.4. Permanent irrigation systems that spray on buildings can cause major structural damage and mold growth. Do not install irrigation systems in locations where they spray directly on buildings.

P1.5. Construction activities affect indoor air quality. Mold protection and changing filters are prerequisites; additional measures are covered under IEQ Credit 4.

## IEQ Credit 2: Low-Emitting Materials

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|---|---|
| 1 to 4 points | 2.1. Receive one point (with a maximum of four) for each of the following products tested with the protocols detailed in the CHPS Material Specifications Section 1350 and found to have chemical concentration under the specified limits:<br>▪ Adhesives, sealants, and concrete sealers.<br>▪ Carpet, resilient flooring.<br>▪ Paint.<br>▪ Building insulation.<br>▪ Gypsum board.<br>▪ Acoustical ceilings or wall panels.<br>▪ Wood flooring, composite wood boards. |

Many common indoor building and surfacing materials contain a variety of carcinogenic and/or toxic chemicals. These chemicals are released into the air and can cause a variety of heath problems, from irritating odors to major health problems. Because a single material can off-gas enough toxins to cause health problems, it is important to evaluate and specify materials that are low emitting, non-irritating, nontoxic, and chemically inert. This is especially important in schools because children are more susceptible than adults to indoor air pollutants.

CHPS has developed sample material specifications to identify materials that will not compromise the health of students and staff. The CHPS material specifications (available from www.chps.net) identify over 60 specific chemicals that have been found to impact human health and the maximum emission levels for each. Designers should request emissions test data from manufacturers to ensure that the chemical emissions are within safe exposure levels.

## IEQ Credit 3: Pollutant Source Control

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|---|---|
| 1 point | 3.1. Design to minimize cross-contamination of regularly occupied areas by chemical pollutants:<br>Control surface dust by covering all exposed dirt, providing walk-off mats at all entrances, and not installing deep-pile carpets;<br>***AND*** where chemical use occurs (including housekeeping areas, chemical mixing areas, copying/print rooms), use structural deck-to-deck partitions with separate outside exhausting, no air recirculation, and negative pressure;<br>***AND*** install low-noise, vented range hoods for all cooking appliances (such as stoves, ovens) and chemical mixing areas in lab or prep spaces;<br>***AND*** provide drains with plumbing appropriate for disposal of liquid waste in spaces where water and chemical concentrate mixing occurs. |
| 1 point | 3.2. Install ducted HVAC returns to avoid the dust and microbial growth issues associated with plenum returns. |
| 1 point | 3.3. Use particle arrestance filtration rated at greater than 65% in all mechanical ventilation systems. |

Credit 3.1. Design to physically isolate activities associated with chemical contaminants from other locations in the building, and provide dedicated systems to contain and remove chemical pollutants from source emitters at source locations. Eliminate or isolate high hazard areas and design all housekeeping chemical storage and mixing areas (central storage facilities and janitors closets) to allow for secure product storage. Design copy/fax/printer/printing rooms with structural deck-to-deck partitions and dedicated exhaust ventilation systems.

Credit 3.2. Plenum returns are easily contaminated with dust and microbial growth. Ducted returns, though more expensive, will help prevent such problems and reduce maintenance and repairs.

Credit 3.3. Filters rated at greater than 65% will remove more pollutants from the air used to ventilate the school.

### IEQ Credit 4: Construction IAQ Management Plan

| | |
|---|---|
| 1 point | 4.1. During construction, meet or exceed all of the following minimum requirements: Temporary construction ventilation: Continuously ventilate during installation of materials that emit Volatile Organic Compounds (VOC) and after instillation until emissions dissipate. Follow the recommended ventilation times in the CHPS Specification Section 1350, or ventilate for 72 hours, if not specified. Ventilate areas directly to outside areas; do not ventilate to other enclosed spaces. If continuous ventilation is not possible via the building's HVAC system(s), then ventilate via open windows and temporary fans that sufficiently provide no less than three air changes per hour.<br>▪ Dust protection: Turn the ventilation system off, and protect HVAC supply and return openings from dust infiltration during dust producing activities (e.g. drywall installation and finishing). Provide temporary ventilation as required.<br>▪ Preconditioning: Allow products that have odors and significant VOC emissions to off-gas in dry, well-ventilated space for a sufficient period to dissipate odors and emissions prior to delivery to the construction site. Condition products without containers and packaging to maximize off-gassing of VOCs. Condition products in a ventilated warehouse or other building. Comply with substitution requirements for consideration of other locations.<br>▪ Sequencing: Where odorous and/or high VOC-emitting products are applied on-site, apply them prior to installation of porous and fibrous materials. Where this is not possible, protect porous materials with polyethylene vapor retarders. .<br>▪ HEPA vacuuming and duct cleaning: Vacuum carpeted and soft surfaces with a high-efficiency particulate arrestor (HEPA) vacuum. If ducts contain dust and dirt, clean them using a HEPA vacuum immediately prior to substantial completion and prior to using the ducts to circulate air. Oil film on sheet metal should be removed before shipment to site. However, ducts will be inspected to confirm that no oil film is present. Remove any oil. |
| 1 points | 4.2. Building shall be flushed-out continuously for at least 30 days prior to substantial completion. When the contractor is required to perform touch-up work, provide temporary construction ventilation during installation and extend the building flush-out by a minimum of four days after touch-up installation, with 100% tempered outside air for 24 hours each day. |

Credit 4.1. Each of the listed construction practices will improve indoor air quality by minimizing the amount of indoor pollutants that are distributed and retained by the surface materials and ventilation systems during construction.

Credit 4.2. Flushing out the building with 100% outside air will help remove indoor pollutants prior to occupancy. Do not "bake out" the building by increasing the temperature of the space.

**Resources**

CHPS Best Practices Manual, Volume II: Guideline GC3: Indoor Air Quality During Construction.

# Acoustics

Purpose: Design HVAC systems and classrooms to provide acoustic levels that do not interfere with student and teacher productivity.

### IEQ Prerequisite 2: Minimum Acoustical Performance

| | |
|---|---|
| *Required* | P2.1. Classrooms must have:<br>▪ Maximum unoccupied background noise levels of 45 dBA.<br>▪ 0.6-second maximum (unoccupied) reverberation times. |

Student learning suffers in acoustically poor environments. Excess noise from exterior sources, loud HVAC systems, or other nearby rooms can make it difficult, and sometimes impossible, for students and teachers to communicate.

The purpose of this prerequisite is to eliminate the worst performing acoustical environments. Background noise levels of 45 dBA are not sufficient for classrooms with young children, students with limited English proficiency, and those with hearing impairments or language disorders. **Districts and designers are strongly encouraged to move beyond these prerequisites and achieve background noise levels of 35 dBA for all classrooms.**

Important aspects of classroom acoustical design include isolation from exterior noise (wind loads, traffic, and other loud outdoor activities), elimination of interior noise (from HVAC systems, foot traffic, and other classrooms), and the use of appropriate wall assembly and interior surface materials to minimize sound propagation and reduce reverberation times in the classrooms. The most common sources of interior mechanical noise are the air conditioning and air-handling systems, including ducts, fans, condensers, and dampers.

Architects and engineers must design to these levels. Verification should be integrated with building commissioning.

**Resources**

National Clearinghouse for Educational Facilities: http://www.edfacilities.org/.

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### IEQ Credit 5: Improved Acoustical Performance

| | |
|---|---|
| 1 point | 5.1. Classrooms must have:<br>- 40 dBA maximum (unoccupied) background noise levels.<br>- 0.6-second maximum (unoccupied) reverberation times. |
| 2 points | 5.2. Classrooms must have:<br>- 35 dBA maximum (unoccupied) background noise levels.<br>- 0.6-second maximum (unoccupied) reverberation times. |

Acousticians recommend 35 dBA as the minimum background levels for school classrooms. Strategies for improving the background noise levels include using centralized HVAC systems and acoustically isolating mechanical equipment from classrooms.

**Resources**

National Clearinghouse for Educational Facilities: http://www.edfacilities.org/.

# Thermal Comfort

Purpose: Provide a high level thermal comfort with individual teacher control of thermal, ventilation, and lighting systems to support optimum health, productivity, and comfort conditions.

**IEQ Prerequisite 3: ASHRAE 55 Code Compliance**

| | |
|---|---|
| *Required* | P3.1. Comply with ASHRAE Standard 55-1992, Addenda 1995 for thermal comfort standards, including humidity control within established ranges per climate zone. Indoor design temperature and humidity conditions for general comfort applications shall be determined in accordance with ANSI/ASHRAE 55-1992 or Chapter 8 of the ASHRAE Handbook, 1993, Fundamentals volume. Note that winter humidification and summer dehumidification shall not be required. The upper limit may be ignored for naturally ventilated buildings. |

**Resources**

CHPS Best Practices Manual, Volume II: HVAC Chapter.

### IEQ Credit 6: Controllability of Systems

| | |
|---|---|
| 1 point | 6.1. Provide a minimum of one operable window in each classroom. |
| 1 point | 6.2. Provide temperature and lighting controls for each classroom. |

Credit 6.1. Operable windows are important for personal comfort, and have been shown to improve student performance. Provide at least one operable window in each classroom. It is recommended to interlock controls with the HVAC system to optimize energy efficiency. Train teachers on how to properly use the HVAC controls in their rooms and how opening door and windows affect ventilation and comfort.

Credit 6.2. Individual classrooms will vary in temperature depending on their orientation and other building conditions, as well as occupant preferences. Provide individual or integrated controls systems to allow teachers to regulate the lighting and temperature of their classrooms.

# DISTRICT RESOLUTIONS

## High Performance Policies

Purpose: Integrate high performance goals into district planning.

**District Credit 1: District Resolutions**

| | |
|---|---|
| 1 point | 1.1. Districts must pass board-level resolutions that integrate high performance standards in the preparation and revision of district educational specifications and building programs, i.e. requiring all new facilities to be high performance schools or prioritizing CHPS high performance schools in local bond funding. |

Districts leaders who institutionalize high performance are not just building better schools; they are protecting student health, improving test scores, and lowering the district's operating expenses. To earn this credit, the district must pass board-level resolutions that reference compliance with the CHPS Eligibility Criteria. The district is free to decide the most appropriate way to integrate the criteria into their specifications and building program. Some districts may take an aggressive leadership role and require that all new schools comply with the CHPS Eligibility Criteria. Others may use a tiered approach: starting with several pilot schools and gradually requiring all schools to comply. Other options include offering additional funds or priority funding in local bond elections. Adding requirements for only specific issues (such as daylighting or energy efficiency) are valuable but do not qualify for this point.

# Indoor Air Quality

Purpose: Protect student and staff health during occupancy.

**District Credit 2: IAQ Management Plan**

| | |
|---|---|
| 1 point | 3.1. Implement the EPA's Tools for Schools Program or an alternative, equivalent in scope and effectiveness. Include the IAQ Management Plan in the Facility Maintenance and Commissioning Plans. Designate a trained staff person with clear responsibility to implement and update the plan. |

The Tools for Schools Kit provides the basic set of operations and maintenance actions that will help prevent IAQ problems in schools. Protecting indoor air quality requires a knowledgeable and responsive staff. Tools for Schools establishes responsibilities and clear communication channels so that indoor air problems can be prevented and problems can be quickly identified and solved.

Failure to respond promptly and effectively to poor indoor air quality in schools can cause severe consequences. These include an increase in short- and long-term health problems (leading to more absenteeism), a greater risk that classrooms or buildings will have to be closed with students and staff temporarily relocated, and potential liability problems.

**Resources**
EPA: http://www.epa.gov/iaq/schools.

# Maintenance

Purpose: Ensure the school continues to perform as it was designed.

**District Credit 3: Maintenance Plan**

| | |
|---|---|
| 1 point | 3.1. In addition to full participation in state deferred maintenance programs, the district must create a school maintenance plan that includes an inventory of all equipment in the school and their preventative maintenance needs. |
| 1 point | 3.2. The school district has allocated an annual budget to fund the maintenance plan at 100% |

Regular maintenance is critically important to the operation and performance of schools. Every district has unique maintenance needs, but districts should invest sufficient staff and resources to ensure that the school's building systems continue to operate as they were designed.

High performance schools are not maintenance-intensive. However, all buildings and building systems require preventative—not just deferred—maintenance. This credit aims to incent districts to proactively plan for preventative maintenance tasks, and invest adequate funds in the maintenance of their school facilities. If cost-effective and appropriate, outsourcing some, or all, of the maintenance tasks may be an option for some districts.

Credit 3.1. The maintenance plan goes beyond deferred maintenance to include all regularly scheduled preventative maintenance tasks over the lifetime of the building system or equipment. These tasks include cleanings, calibrations, component replacements, and general inspections. The commissioning plan and maintenance documentation is an excellent starting point and reference for developing the maintenance plan. The plan must include staff time and materials costs for each maintenance task and clearly define who is responsible for performing the task, as well as the overall management of maintenance activities.

Credit 3.2. Maintenance plans have limited value if they are not implemented. To earn this point, the plan created in Credit 3.1 must be funded at 100%. This may mean the expansion of current staff and/or increases in the amount spent on preventative maintenance tasks.

## Energy

Purpose: Specify energy efficient equipment to minimize energy loads and operational costs. Encourage the development and use of grid-source, renewable energy technologies on a net-zero pollution basis.

### District Credit 4: Equipment Performance

Choose *ONE* of the following credits:

| | |
|---|---|
| 1 point | 4.1. Districts must pass a resolution to require ENERGY STAR® equipment and appliances for all new purchases, and to prohibit the purchase of low efficiency products, including halogen torchieres and portable electrical resistance heaters. |
| 2 points | 4.2. Districts must pass a resolution to require new equipment and appliances that are within 20% of the EPA's ENERGY STAR® "best available" for the category, and to prohibit the purchase of low efficiency products including halogen torchieres and portable electrical resistance heaters. |

Credits 4.1 and 4.2. The ENERGY STAR® program maintains a database of compliant manufacturers and products. To earn this credit, the district must pass a board-level resolution requiring that all new equipment or appliances be ENERGY STAR® -compliant. Products not currently covered under the ENERGY STAR® program are excluded from the scope of this credit. A partial list of equipment covered by ENERGY STAR® includes computers, monitors, copy machines, water coolers, printers, scanners, refrigerators, and washing machines.

In addition, the resolution must state that the district cannot purchase halogen torcheires and portable electrical resistance heaters.

**Resources:**
ENERGY STAR®: www.energstar.org.

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**District Credit 5: Green Power**

| | |
|---|---|
| 2 points | 5.1. Engage in a two-year contract to purchase power generated from renewable sources approved by the California Energy Commission. |

Purchase power from a provider that guarantees a fraction of its delivered electric power is from net nonpolluting renewable technologies. The California Energy Commission approves sources for consumers in California. Grid power that qualifies for this credit originates from solar, wind, geothermal, biomass, or low-impact hydro sources. Low-impact hydro complies with the Low Impact Hydropower Certification Program.

**Resources**

California Energy Commission: http://www.energy.ca.gov/greenpower/index.html.
Toll Free: 800-555-7794.
E-mail: renewable@energy.state.ca.us

# Transportation

Purpose: Lower the environmental impact of district bus and maintenance vehicle fleets.

**District Credit 6: Buses and Alternative Fueled Vehicles**

| | |
|---|---|
| 1 point | 6.1. Provide bus service for students. |
| 1 point | 6.2. Alternative fueling. At least 20% of the district-owned buses and maintenance vehicles serving the school must use alternative fuels. If district bus service is provided under contract from a third party, then 20% of the buses used to service the school must use alternative fuels. |

Transporting children to and from school requires significant energy, time, and money, and causes a considerable amount of pollution. Intelligent transportation strategies for bus and maintenance fleets save resources, lower pollution, and protect student health.

Credit 6.1. This credit aims to reduce the number of parents independently driving their children to school. When designed appropriately, district-provided bus services are large investments that can greatly reduce reliance on automobiles while increasing convenience to parents. However, buses should not be encouraged if they are not needed. School-provided busing is less sustainable than walking, biking, or using municipal transit.

Credit 6.2. When used, buses should operate on alternative fuels. Most school buses are old and emit 60 to 70 times more smog-forming pollutants, and hundreds of times more toxic air contaminants, than today's passenger cars. In addition, new research has shown that pollutants, including carcinogens and particulates, *inside* the buses can be alarmingly high. These pollutants can have direct and significant effects on student health.

Replacing older school buses will improve public health and safety. Currently, propane, natural gas and other alternative fuels are used in less than 1 % of school buses nationwide. There are funds available from the California Energy Commission and Air Resources Board to help districts retrofit or replace old vehicles.

# CRITERIA SCORECARD

Credits in bold font = **CHPS-recommended credits**

## Site 14 points

| | | | | | ✓ |
|---|---|---|---|---|---|
| Site Selection | Prereq 1 | Code Compliance | R | P1.1. Comply with all requirements of Title 5. | |
| | Credit 1 | Sustainable Site Selection | 1 | 1.1. No development on sites that are: prime agricultural land, in flood zone, habitat for endangered species, parkland. | |
| | | | 1 | 1.2. Do not develop on greenfields. | |
| | | | 1 | 1.3. Create centrally located sites with in which 50% of students are located within minimum distances of the school. | |
| | | | 1 | 1.4. Joint use of facilities. | |
| | | | 1 | 1.5. Joint use of parks. | |
| | | | 1 | 1.6. Reduce building foot print. | |
| Transportation | Credit 2 | Transportation | 1 | 2.1. Near public transit. | |
| | | | 1 | 2.2. Provide bike racks and bike lanes for 15% of school population. | |
| | | | 1 | 2.3. Minimize parking lot and create preferred parking for carpools. | |
| Stormwater Management | Prereq 2 | Construction Erosion | R | P2.1. Control erosion and sedimentation to reduce negative impacts on water and air quality. | |
| | Credit 3 | Post-construction Management | 1 | 3.1. Minimize runoff. | |
| | | | 1 | 3.2. Treat runoff. | |
| Outdoor Surfaces | Credit 4 | Design to Reduce Heat Islands | 1 | 4.1. Shade or lighten impervious areas, or reduce impervious parking. | |
| | | | 1 | 4.2. Install cool roof. | |
| Outdoor Lighting | Credit 5 | Light Pollution Reduction | 1 | 5.5. Minimize outdoor illumination with no direct beam leaving site. | |

## Water 5 points

| | | | | | ✓ |
|---|---|---|---|---|---|
| Outdoor Systems | Prereq 1 | Create Water Use Budget | R | P1.1. Establish and comply with water use budget. | |
| | Credit 1 | Reduce Potable Water for Landscaping | 1-2 | 1.1. Use high efficiency irrigation technology, OR, reduce potable water consumption for irrigation by 50%.<br>*(2 points = 100% or no irrigation installed)* | |
| Indoor Systems | Credit 2 | Water Use Reduction | 1 | 2.1. 50% reduction in potable water use for sewage conveyance with reclaimed water. | |
| | | | 1-2 | 2.2. Decrease water use by 20% after meeting Energy Policy Act.<br>*(2 points = 30% reduction)* | |

648

## Energy 24 points ✔

| | | | | | |
|---|---|---|---|---|---|
| Energy Efficiency | Prereq 1 | Minimum Energy Performance | R | P1.1. Design building to exceed Title 24-2001 by 10%., or include prescriptive package of measures. | |
| | **Credit 1** | **Superior Energy Performance** | **2-10** | **1.1. 15% to 35% reduction in total net energy use from Title 24-2001 baseline, or include prescriptive package of measures.** | |
| | **Credit 2** | **Natural Ventilation** | **1** | **2.1. HVAC Interconnect controls with operable windows & doors.** | |
| | | | **3** | **2.2. Design 90% of classrooms without air conditioning.** | |
| Alternative Energy Sources | Credit 3 | Renewable Energy | 2-6 | 3.1. 5% to 50% of net energy use supplied by renewable energy or distributed generation. | |
| Commissioning and Verification | Prereq 2 | System Testing & Training | R | P2.2. Third party or district verification of building systems & training. | |
| | **Credit 4** | **Commissioning** | **2-3** | **4.1. Basic commissioning tasks.**<br>***(2 points = advanced building commissioning)*** | |
| | Credit 5 | Energy Management Systems | 1 | 5.1. Install an Energy Management System to measure and control loads. | |

## Materials 11 points ✔

| | | | | | |
|---|---|---|---|---|---|
| Waste Reduction and Efficient Material Use | Prereq 1 | Storage and Collection of Recyclables | R | P1.1. Meet local standards or recycling space and have spaces dedicated to recycling. | |
| | **Credit 1** | **Site Waste Management** | **1-2** | **1.1. Meet local ordinances, develop waste management plan, and recycle/salvage 50% construction waste.**<br>***(2 points = 75% reduction)*** | |
| | Credit 2 | Building Reuse | 1-3 | 2.1. Reuse 75% of previous structure.<br>*(2 points = reuse of 100% of previous structure)*<br>*(3 points = reuse of 100% of previous structure and 50% of non-shell systems)* | |
| | Credit 3 | Resource Reuse | 1-2 | 3.1. Specify salvaged or refurbished materials for 5% of building.<br>*(2 points = specification of 10%)* | |
| Sustainable Materials | **Credit 4** | **Recycled Content** | **1-2** | **4.1. 25% of building materials meet requirements.**<br>***(2 points = 50% of building materials meet requirements)*** | |
| | Credit 5 | Rapidly Renewable Materials | 1 | 5.1. 5% of materials are rapidly renewable. | |
| | **Credit 6** | **Certified Wood** | **1** | **6.1. 50% of wood must be certified.** | |

## IEQ 17 points ✓

| | | | | | |
|---|---|---|---|---|---|
| Daylighting | **Credit 1** | **Daylighting in Classrooms** | 3 | **1.1. Minimum 2% daylight factor in 75% of classrooms.** | |
| | | | 1 | **1.2. Direct line of site glazing for 90% of classrooms.** | |
| Indoor Air Quality | Prereq 1 | Minimum Requirements | R | P1.1. HVAC must meet Title 24 ventilation requirements, Cal/OSHA performance requirements, and satisfy ASHRAE 62 requirements for outdoor air supply. | |
| | **Credit 2** | **Low-Emitting Materials** | 1-4 | **2.1. Building materials (paints, ceiling tiles, carpet, adhesives, etc) meet chemical emission rates detailed in CHPS material specifications.** | |
| | **Credit 3** | **Pollutant Source Control** | 1 | **3.1. Control dust, segregate pollutant sources, local exhaust in kitchens, appropriately plumbed drains in chemical storage areas.** | |
| | | | 1 | **3.2. Install ducted HVAC returns.** | |
| | | | 1 | **3.3. Use high efficiency filters.** | |
| | **Credit 4** | **Construction IAQ Management Plan** | 1 | **4.1. Create and implement specified construction IAQ plan.** | |
| | | | 1 | **4.2. Flush out building or conduct IAQ testing.** | |
| Acoustics | Prereq 2 | Minimum Acoustical Performance | R | P2.1. Classrooms must have a maximum (unoccupied) noise level of 45dbA, with maximum (unoccupied) reverberation times of 0.6 sec. | |
| | **Credit 5** | **Improved Acoustical Performance** | 1 | **5.1. Classrooms must have a maximum (unoccupied) noise level of 40dbA, with maximum (unoccupied) reverberation times of 0.6 sec.** | |
| | | | 2 | **5.2. Classrooms must have a maximum (unoccupied) noise level of 35dbA, with maximum (unoccupied) reverberation times of 0.6 sec.** | |
| Thermal Comfort | Prereq 3 | ASHRAE 55 Code Compliance | R | P3.1. Comply with Title 24 required ASHRAE 55-1992 thermal comfort standard. | |
| | Credit 6 | Controllability of Systems | 1 | 5.1. Operable windows in classrooms. | |
| | | | 1 | 5.2. Temperature and lighting controls in all classrooms. | |

## District Resolutions 10 points ✓

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|---|---|---|---|---|---|
| Institutionalize High Performance | Credit 1 | District Resolutions | 1 | 1.1. Institutionalize High Performance Goals on a district level. | |
| Indoor Air Quality | Credit 2 | IAQ Management Plan | 1 | 2.1. Create IAQ Management Plan and include in Facility Maintenance and Commissioning Plans. Designate a trained staff person with clear responsibility to implement and update the plan. | |
| **Maintenance** | **Credit 3** | **Maintenance Plan** | 1 | **3.1. Create a maintenance plan that includes an inventory of all equipment in the school and their preventative maintenance needs.** | |
| | | | 1 | **3.2. District allocates budget to fund plan at 100%.** | |
| Energy | Credit 4 | Equipment Performance | 1 | 4.1. Require EnergyStar equipment and prohibit wasteful technologies. | |
| | | | 2 | 4.2. Require new equipment to be within 20% of the EPA ENERGY STAR® "best available" for the category. | |
| | Credit 5 | Green Power | 2 | 5.1. Engage in a two-year contract to purchase power generated from renewable sources approved by the CEC. | |
| Transportation | Credit 6 | Buses and Alternative Fueled Vehicles | 1 | 6.1. Provide busing service. | |
| | | | 1 | 6.2. Alternative Fueled Vehicles. 20% of bus and maintenance vehicle fleet serving the school must use alternative fuels. | |

Minimum total required for CHPS School (Two points must be in Energy category) 28